

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3645

WIND-TUNNEL INVESTIGATION OF EFFECTS OF FUSELAGE
CROSS-SECTIONAL SHAPE, FUSELAGE BEND, AND VERTICAL-TAIL
SIZE ON DIRECTIONAL CHARACTERISTICS OF NONOVERLAP-TYPE
HELICOPTER FUSELAGE MODELS WITHOUT ROTORS

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Langley Field, Va.



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SUMMARY

A low-speed investigation was made in the Langley stability tunnel to determine the directional stability characteristics of tandem nonoverlap-type helicopter fuselages without rotors. The investigation consisted of a study of both bent and straight fuselages having either circular or essentially elliptical cross sections and with two vertical-tail sizes.

The results of this investigation indicate that a straight fuselage with circular cross sections, in general, had a more nearly linear variation of yawing-moment coefficient with angle of sideslip and a smaller variation of directional stability with angle of attack than the bent and straight fuselage models with elliptical cross sections and a bent fuselage with a circular cross section. Changing the cross-sectional shape from elliptical to circular resulted in a more nearly linear variation of yawing-moment coefficient with angle of sideslip and a smaller variation of directional stability with angle of attack. Adding the bend in the fuselage, in general, made the adverse effects of flattening the fuselage cross section more pronounced. The basic twin vertical tails, each having an area of 46.30 square inches, did not provide directional stability throughout the angle-of-attack range for any of the models investigated; however, twin vertical tails of about $2\frac{1}{4}$ times this area provided a substantial improvement in the directional stability for all models.

INTRODUCTION

The results of flight tests have shown that a tandem nonoverlap type of helicopter (a helicopter with nonoverlapping rotors) with a bent-fuselage form and a relatively deep elliptical nose section was directionally unstable at positive angles of attack and that this instability

was particularly undesirable in the autorotative and partial-power-descent flight conditions (ref. 1). A wind-tunnel investigation (ref. 2) of a model of this helicopter configuration, without rotors, has shown that the directional stability of the fuselage varied a large amount with angle of attack and that this variation of directional stability was associated with the rate of change with sideslip angle of an asymmetric trailing vortex system that existed on the fuselage. These characteristics are not commonly encountered with straight, relatively circular fuselages used for airplanes.

The use of spoilers around the nose of the fuselage resulted in an improvement in the directional stability characteristics of this configuration by reducing the unstable yawing moment obtained with the fuselage alone. These spoilers, of course, resulted in an increase in drag.

Since the bend in the fuselage of the nonoverlap-type helicopter may be necessary for rotor and ground clearance, an experimental investigation was made in the Langley stability tunnel in order to determine the relative influence of the fuselage cross-sectional shape and fuselage bend on the directional stability characteristics. As in the investigation of reference 2, these models were tested without rotors.

The present investigation consisted in the measurements of the aerodynamic forces and moments throughout a range of sideslip angles at four angles of attack for the models both without tails and with two sizes of twin vertical tails. The fuselage models used in this investigation were: a bent fuselage (fuselage 3 of ref. 2), a straight fuselage with essentially elliptical cross section at the nose, and both a bent fuselage and a straight fuselage with circular cross sections. All fuselages had, in general, the same longitudinal distribution of cross-sectional area.

SYMBOLS

The data presented herein are referred to the wind system of axes with the origin at the assumed centers of gravity of the fuselages. The positive directions of forces, moments, and angles are shown in figure 1. The symbols and coefficients employed are defined as follows:

A	vertical-tail aspect ratio, b^2/S_t
b	vertical-tail height, ft
\bar{c}_t	vertical-tail mean aerodynamic chord, ft

c_t	vertical-tail chord, ft
d	distance between vertical tails, ft
l	distance between rotor hub centers, 4.23 ft
l_t	tail length (distance from center of gravity to $c_t/4$ of vertical tail measured parallel to fuselage reference line), ft
$2S_d$	total rotor disk area, 26.39 sq ft
S_t	area of one vertical tail, sq ft
t	tail thickness, ft (see fig. 3)
V	free-stream velocity, ft/sec
q	dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
ρ	mass density of air, slugs/cu ft
α	angle of attack of fuselage reference line, deg
β	angle of sideslip, deg
λ_t	vertical-tail taper ratio
C_D	drag coefficient, $\frac{\text{Drag}}{q2S_d}$
C_Y	side-force coefficient, $\frac{\text{Side force}}{q2S_d}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{q2S_d l}$
$C_{n,t}$	yawing-moment coefficient attributable to vertical tail

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qS_d l}$

$$C_{n\beta} = \frac{\partial C_n}{\partial \beta} \text{ (slope of } C_n \text{ through } \beta = 0^\circ)$$

$$C_{n\beta, t} = (C_{n\beta} \text{ for fuselage with tail}) - (C_{n\beta} \text{ for the fuselage alone})$$

Component designations:

T_1 tail 1 (tail 5 of ref. 2), (see fig. 3)

T_2 tail 2 (see fig. 3)

F_1, F_2, F_3, F_4 fuselages 1, 2, 3, and 4, respectively (see fig. 2)

MODELS, APPARATUS, AND TESTS

The nonoverlap-type helicopter fuselage models used in this investigation were made of laminated mahogany and are shown in figure 2. These models are designated herein as:

F_1 , bent fuselage with basic cross section referred to hereinafter as elliptical

F_2 , bent fuselage with circular cross section

F_3 , straight fuselage with elliptical cross section

F_4 , straight fuselage with circular cross section

Each fuselage had the same cross-sectional shape (either circular or elliptical) throughout with the exception of fuselage F_1 where the elliptical section becomes somewhat distorted rearward of the center of gravity. All fuselages had approximately the same longitudinal distribution of cross-sectional area. These fuselages were the same length as fuselage 3 of reference 2 which was a 1/10-scale model of a present-day tandem-helicopter fuselage. The vertical tails T_1 and T_2 (fig. 3) used in the present tests were made of 1/4-inch-thick plywood (T_2 had

approximately $2\frac{1}{4}$ times the area of T_1). Photographs of the test fuselages with T_1 are presented as figure 4. Configuration F_3T_2 is shown mounted on a support strut in figure 5.

The models were mounted rigidly to a single strut support, at a point midway between the rotor hubs, in the 6-by 6-foot square test section of the Langley stability tunnel. The forces and moments were measured by means of a six-component mechanical balance system.

Except for a few cases, all tests were made at a dynamic pressure of 39.7 pounds per square foot which corresponds to a Mach number of about 0.17. The test Reynolds number was 5.50×10^6 based on the overall fuselage length. Three tests with the F_2T_2 configuration were made at a dynamic pressure of 24.9 pounds per square foot which corresponds to a Mach number of about 0.13 and a Reynolds number of 4.36×10^6 . The angles of sideslip investigated for all configurations ranged from about -25° to 25° at angles of attack of -30° , -10° , 10° , and 30° . The horizontal tail was set at an angle of incidence of approximately 9° for all tail-on tests.

CORRECTIONS

The data obtained in this investigation were not corrected for support-strut interference or blockage effects with the exception of the drag coefficient, which was corrected only for tares. In general, previous tests have indicated that these corrections are not important to the interpretation of these results.

RESULTS AND DISCUSSION

Presentation of Data

The basic data in the form of yawing-moment coefficients plotted against β are presented in figure 6 for the fuselages with tail 1 (T_1), in figure 7 for the fuselages alone, in figure 8 for the isolated tail (T_1) and the contribution of the tail to the yawing-moment coefficient, and in figure 9 for the fuselages with tail 2 (T_2). A plot of the directional stability parameter C_{n_β} (measured through $\beta = 0^\circ$) against α for the fuselages alone and fuselages with T_1 and T_2 is presented as

figure 10. In figure 11 is presented the contribution of the tails to the directional stability as expressed by the yawing-moment coefficient of the fuselage-tail combination minus the yawing-moment coefficient of the fuselage. Also presented in figure 11 are experimental and calculated data for isolated tail T_1 and calculated data for T_2 . The drag coefficient plotted against α is presented as figure 12 for the fuselages alone and for the fuselages with T_1 . Since the purpose of the present paper is to provide an evaluation of the directional stability, only the yawing-moment data are discussed. The side-force and rolling-moment coefficients were also obtained, however, and are presented in figures 13 to 18 without discussion.

Directional Characteristics of Fuselage With and Without T_1

Of all the configurations investigated, F_4T_1 (straight fuselage with circular cross section) has the most nearly linear yawing-moment characteristics (see fig. 6) and the smallest variation of $C_{n\beta}$ (measured through $\beta = 0^\circ$) with angle of attack (see fig. 10). Configuration F_4T_1 generally had about neutral stability for the angle-of-attack range investigated with the exception of $\alpha = 10^\circ$. These data indicate, to a large degree, that the vertical tail (T_1) is not of sufficient size to provide much directional stability.

An examination of the data for the remaining configurations F_1T_1 , F_2T_1 , and F_3T_1 (figs. 6 and 10) shows that, in general, F_3T_1 has better stability characteristics than either F_2T_1 or F_1T_1 since its directional stability varied, in comparison, only a small amount with angle of attack. The results for the bent-fuselage models (F_2T_1 and F_1T_1) show that the directional stability varied a large amount with angle of attack; however, the magnitude of this effect was smaller for F_2T_1 than for F_1T_1 . (See figs. 6 and 10.)

The effect of cross-sectional shape on the yawing-moment characteristics for the bent and straight fuselages can be seen from a study of figures 6 and 10. These results show that, for the bent fuselages, changing from elliptical cross section to circular cross section generally resulted in a more nearly linear curve of C_n with β and less variation of $C_{n\beta}$ with angle of attack. This effect of cross-sectional shape is similar to the results for airplane fuselages with a deep cross section. (See refs. 3 and 4.) Results for the straight fuselages with tail T_1 (figs. 6(c), 6(d), and 10) show generally a similar, although somewhat

smaller, effect of cross section. In general, the bend in the fuselage makes the adverse effect of flattening the fuselage cross section more pronounced. (See figs. 6 and 10.)

The results of figures 7 and 10 show, in general, that the effect of cross section and bend on the yawing-moment characteristics for the fuselages alone are similar to the results obtained for the complete model. The use of circular cross section F_2 instead of elliptical cross section F_1 for the bent fuselages resulted generally in a more nearly linear variation of C_n with angle of sideslip β and in a smaller variation of $C_{n\beta}$ with angle of attack. These effects, however, were somewhat less for the straight fuselages F_3 and F_4 . (See figs. 7 and 10.) A comparison of the data of fuselages F_1 and F_3 and fuselages F_2 and F_4 indicates that not only did the bend cause a less linear variation of C_n with angle of sideslip and increase the variation of $C_{n\beta}$ with angle of attack, but also the fuselage alone was directionally stable at certain angles of attack for a limited sideslip range which is not usually the case for a fuselage alone.

The results of figures 8 and 11 show that the vertical tail T_1 , when mounted on any of the fuselages, is considerably affected by adverse fuselage sidewash, which generally results in a tail effectiveness considerably smaller at a given sideslip angle than that of the isolated-tail assembly. The sidewash effect probably causes the erratic variation of yawing-moment coefficient at large angles of sideslip for the complete model which is not generally present for the fuselages without tail. (Compare figs. 6 and 7.)

The $C_{n\beta,t}$ results calculated with the aid of references 5 and 6 for the isolated tail (fig. 11) are in fair agreement with the measured results. The differences between calculated and measured data may be the result of failure to include the end-plate effect of the horizontal tail in the calculated isolated tail values.

Directional Characteristics of Fuselage with Tail T_2

The effect of substituting T_2 (a tail with about $2\frac{1}{4}$ times the area of T_1) in place of T_1 can be seen by comparing the data of figures 6 and 9. As was expected, the tail T_2 resulted in a substantial improvement in the directional stability characteristics for all fuselage models; however, the erratic behavior of the yawing-moment-coefficient curves with angle of sideslip (fig. 9) was still apparent.

A study of the yawing-moment results of figures 6 and 9 and of the directional stability parameter $C_{n\beta}$ for the configurations with T_1 or T_2 (fig. 10) and the corresponding contribution of T_1 and T_2 to the directional stability parameter $C_{n\beta,t}$ (fig. 11) indicates that, except for magnitude, the effect of changing the fuselage cross section and the effect of bend when T_2 is used is similar to that for the fuselages with T_1 .

CONCLUSIONS

The results of a low-speed investigation in the Langley stability tunnel to determine the directional stability characteristics of nonoverlap-type tandem helicopter fuselage models has indicated the following conclusions:

1. A straight fuselage model with circular cross section, in general, had a more nearly linear variation of yawing-moment coefficient with angle of sideslip and a smaller variation of directional stability with angle of attack than bent and straight fuselage models with essentially elliptical cross section or than a bent fuselage with circular cross section.

2. Changing the fuselage cross-sectional shape from elliptical to circular cross section resulted in a more nearly linear variation of yawing-moment coefficient with angle of sideslip and in a smaller variation of directional stability with angle of attack. Adding the bend in the fuselage, in general, made the adverse effects of flattening the fuselage cross section more pronounced.

3. Twin vertical tails (each having an area of 46.30 square inches) did not provide directional stability throughout the angle-of-attack range for any of the models investigated; however, twin vertical tails of about $2\frac{1}{4}$ times this area provided a substantial improvement in the directional stability for all models.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 19, 1956.

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2. Williams, James L.: Directional Stability Characteristics of Two Types of Tandem Helicopter Fuselage Models. NACA TN 3201, 1954.
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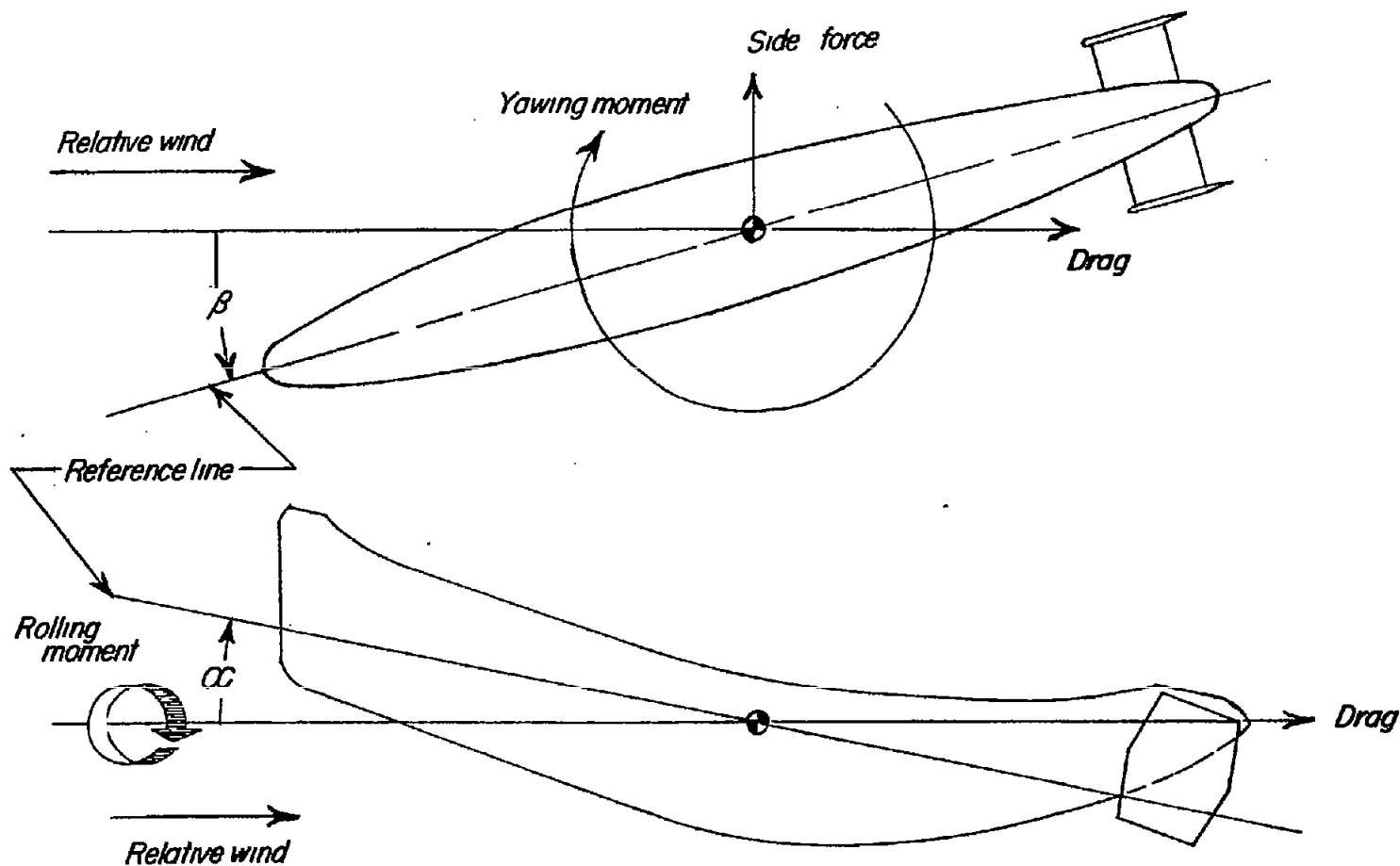


Figure 1.- System of wind axes. Arrows indicate positive direction of forces, moments, and angles.

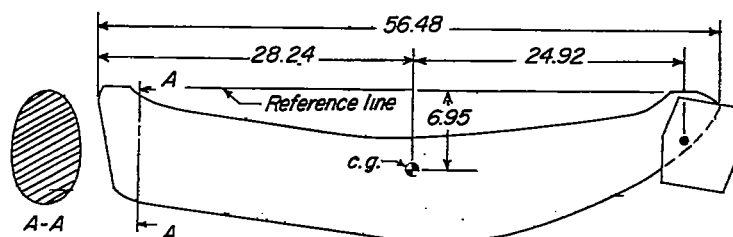
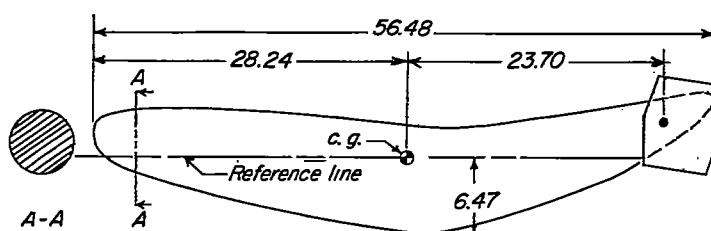
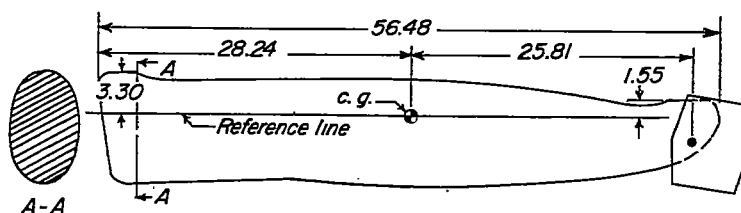
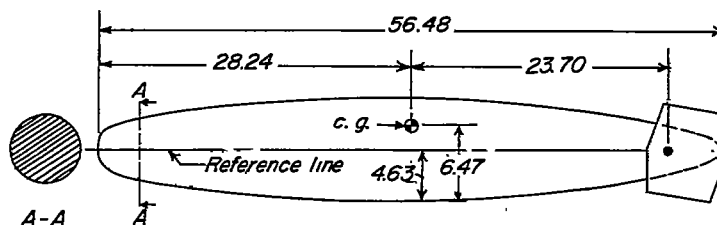
(a) Configuration F_1T_1 .(b) Configuration F_2T_1 .(c) Configuration F_3T_1 .(d) Configuration F_4T_1 .

Figure 2.- Details of nonoverlap-type fuselages. All dimensions are in inches.

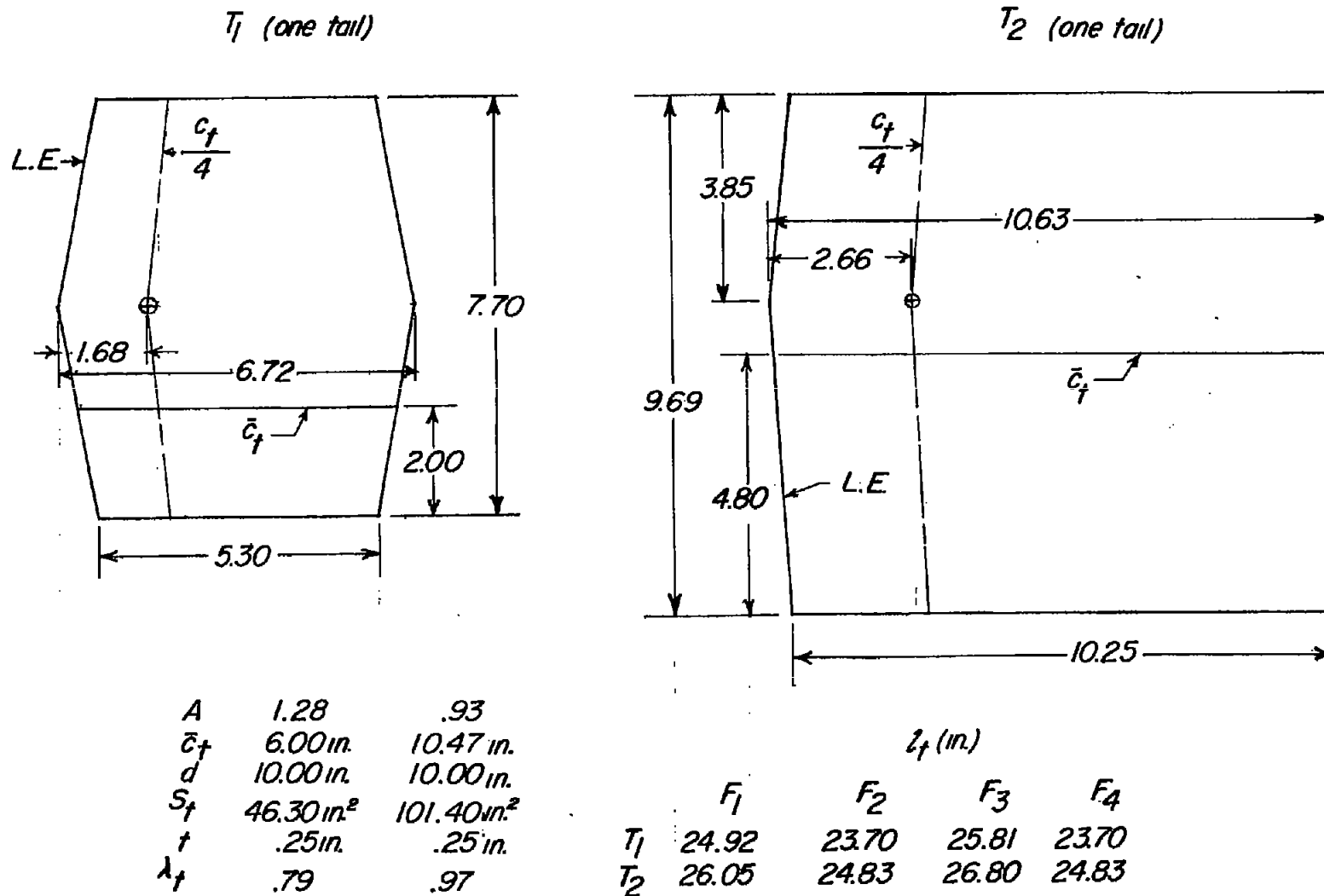
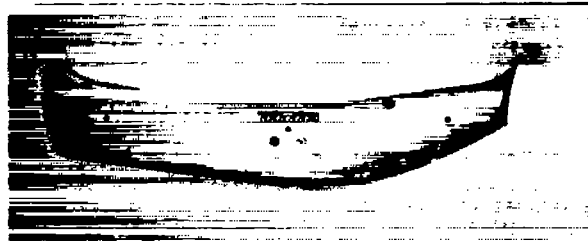
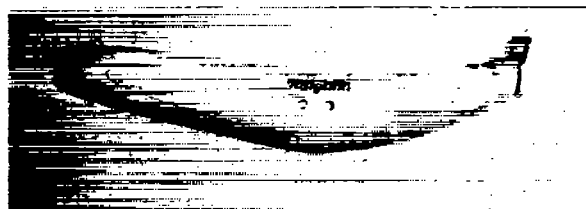


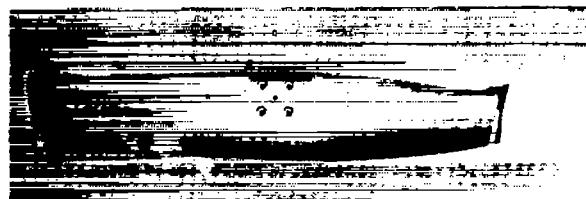
Figure 3.- Vertical tails used in tests. All dimensions are in inches.



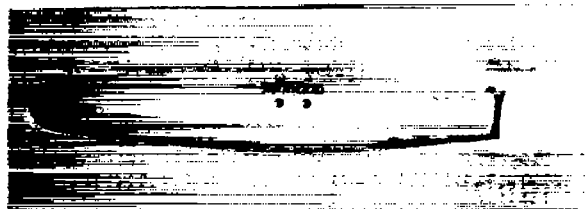
L-87048

(a) Configuration F_1T_1 (fuselage 3 of reference 2).

L-87049

(b) Configuration F_2T_1 .

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(c) Configuration F_3T_1 .

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(d) Configuration F_4T_1 .

Figure 4.- Views of models of fuselages for nonoverlap-type helicopter with tail T_1 .

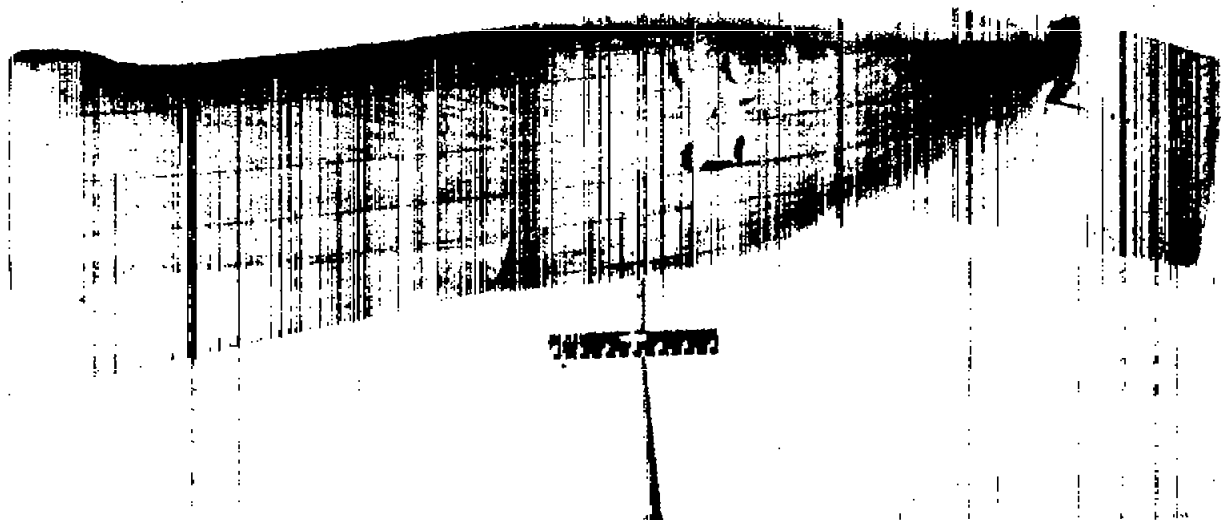


Figure 5.- View of configuration F_3^T L-87052

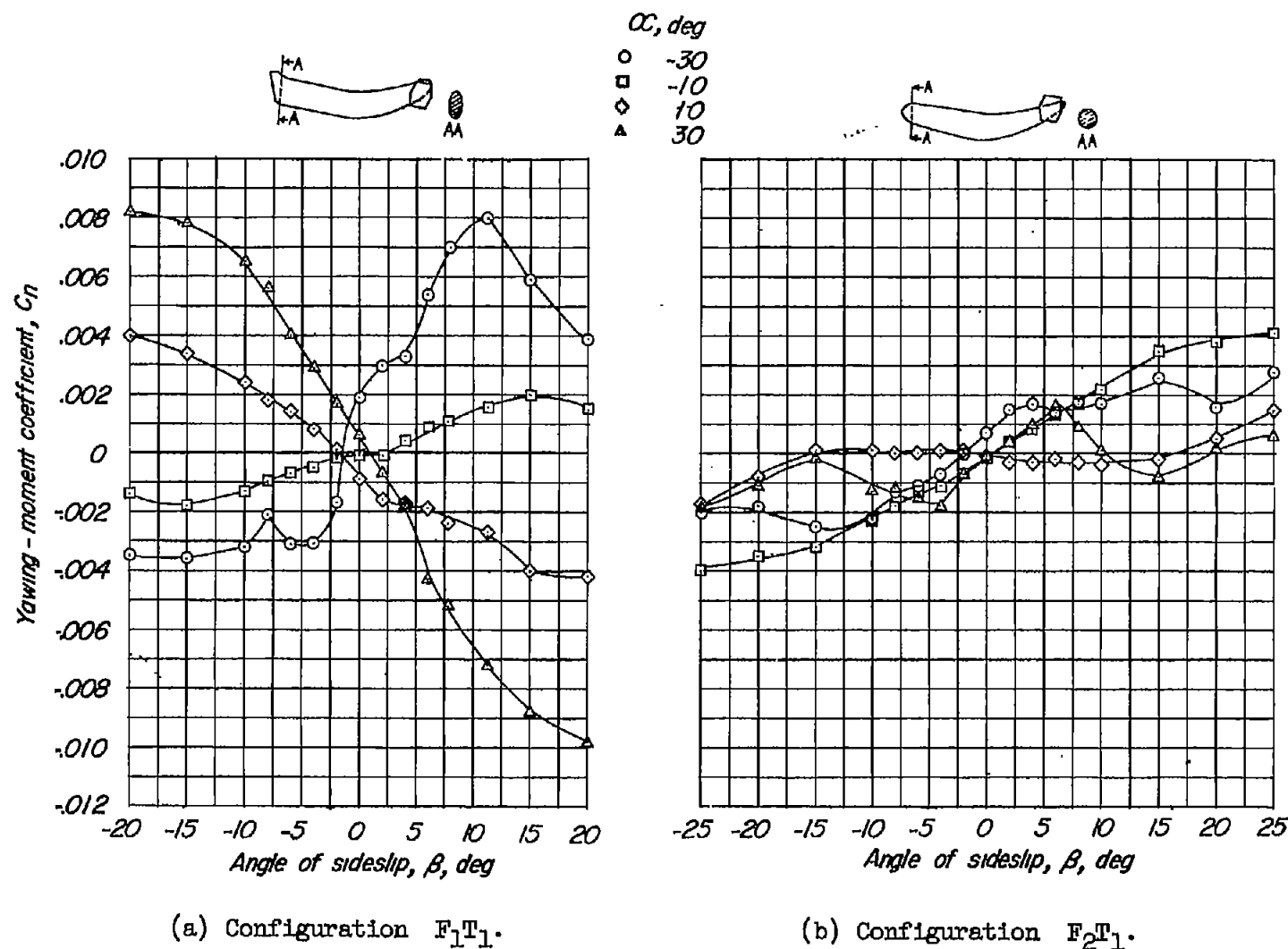


Figure 6.- Yawing-moment characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.

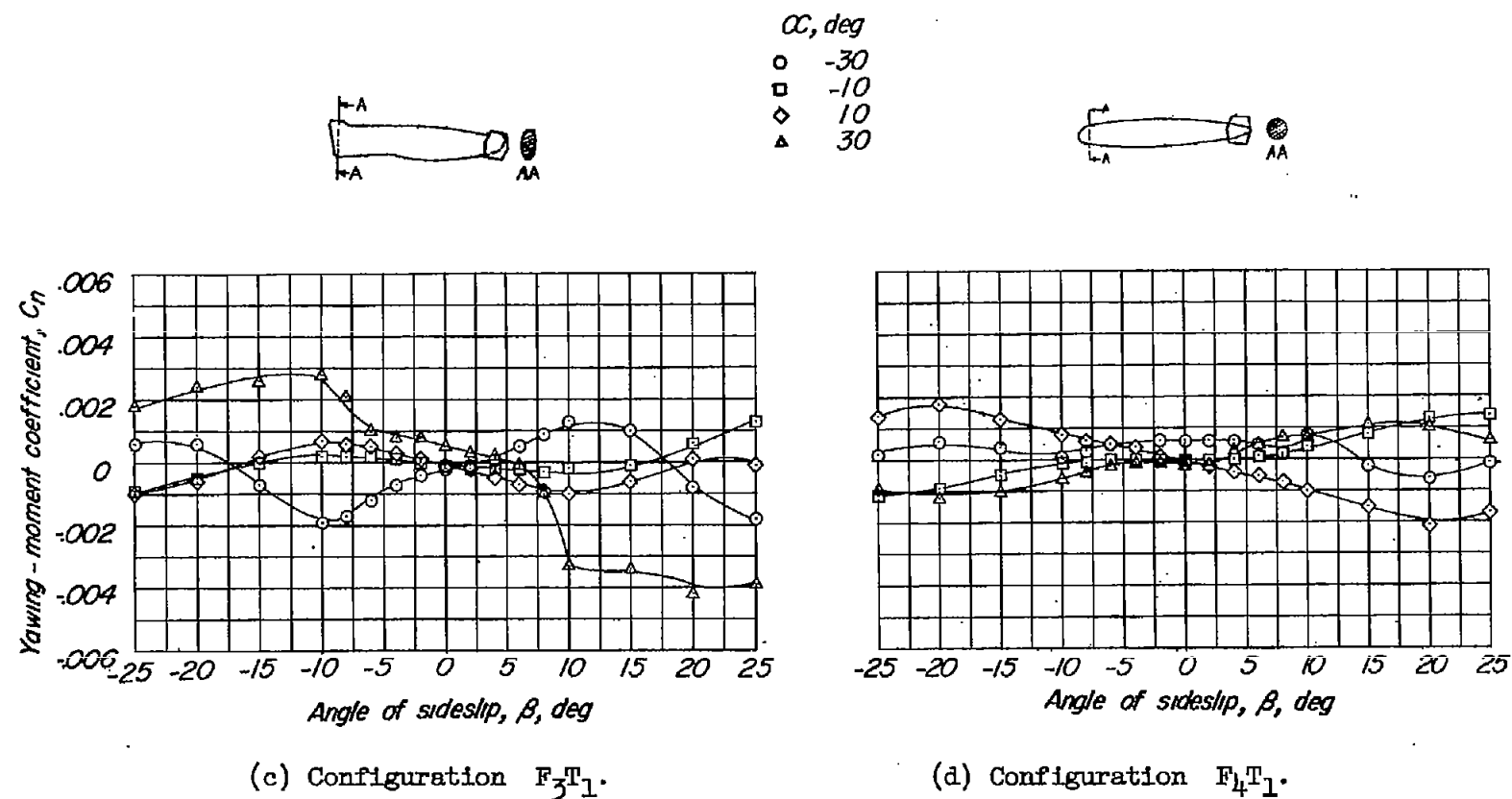


Figure 6.- Concluded.

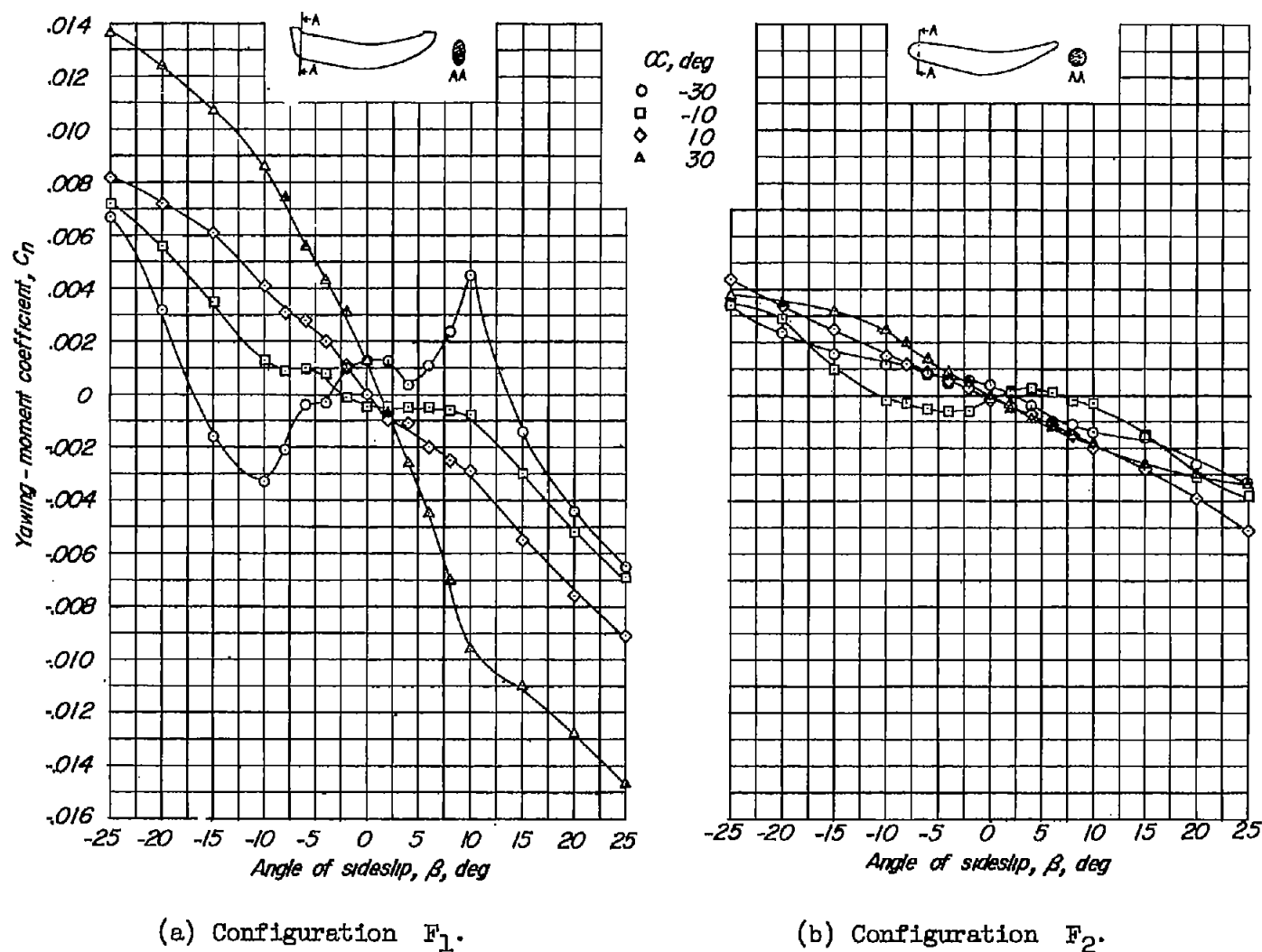


Figure 7.-- Yawing-moment characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.

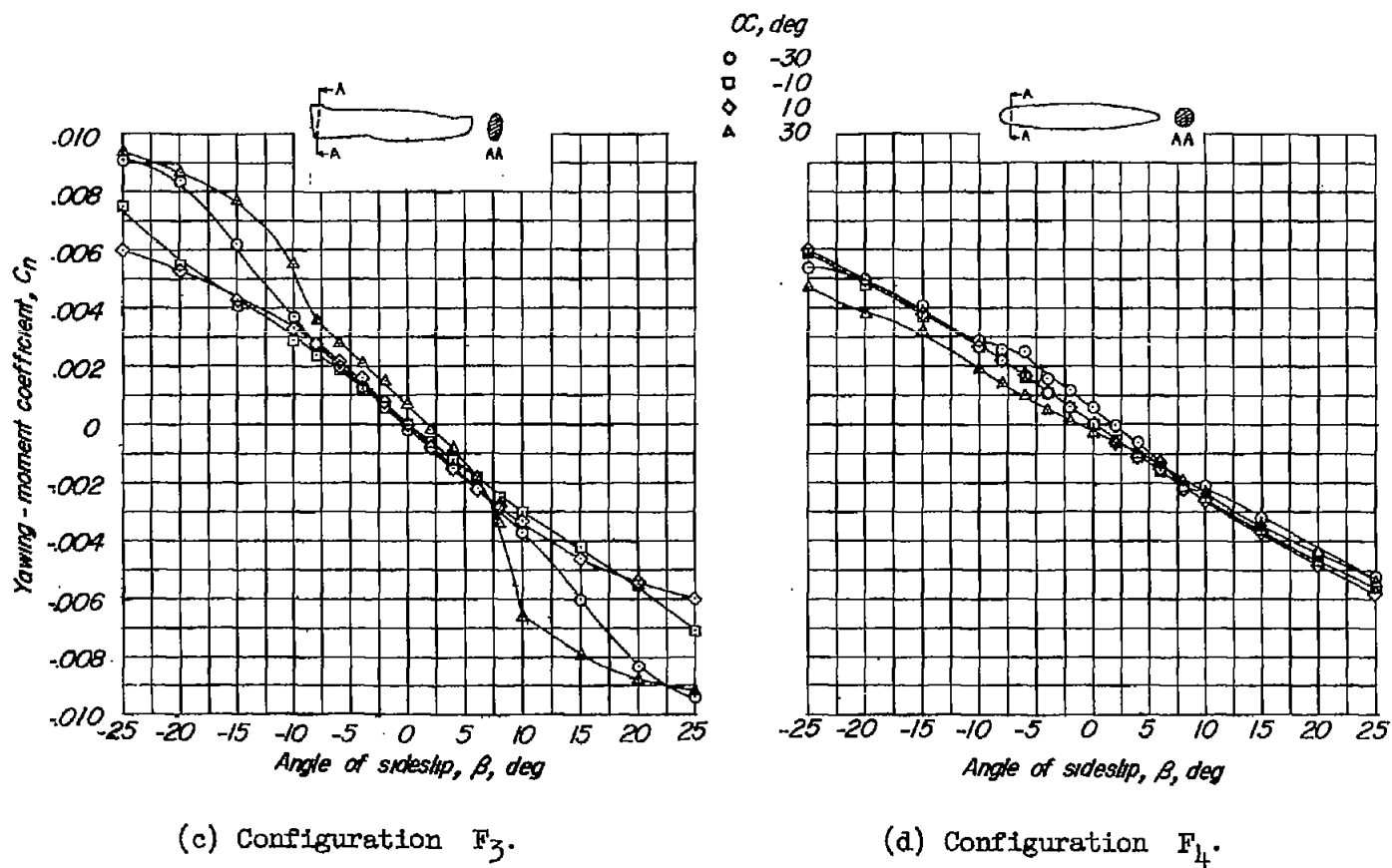


Figure 7.- Concluded.

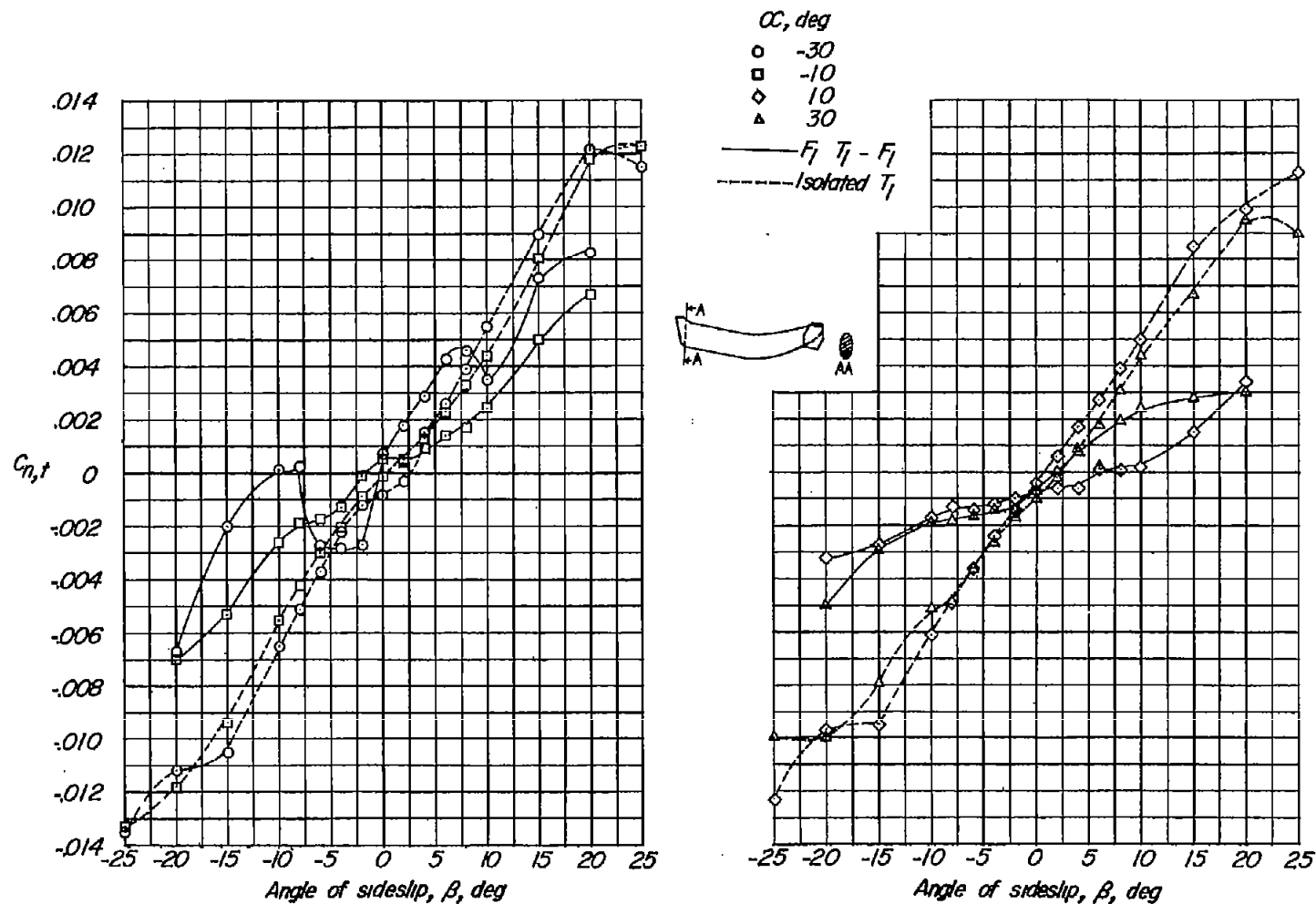
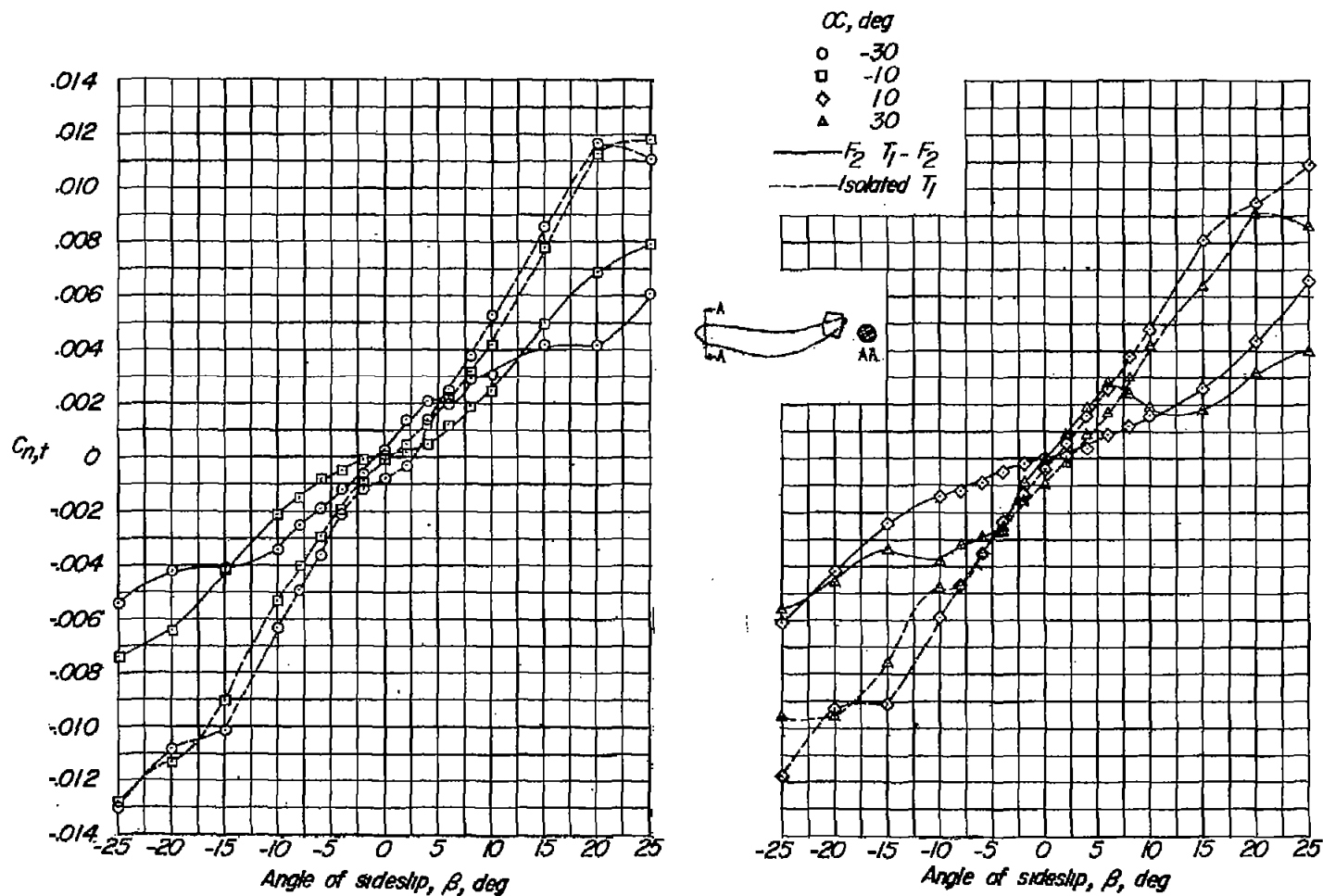
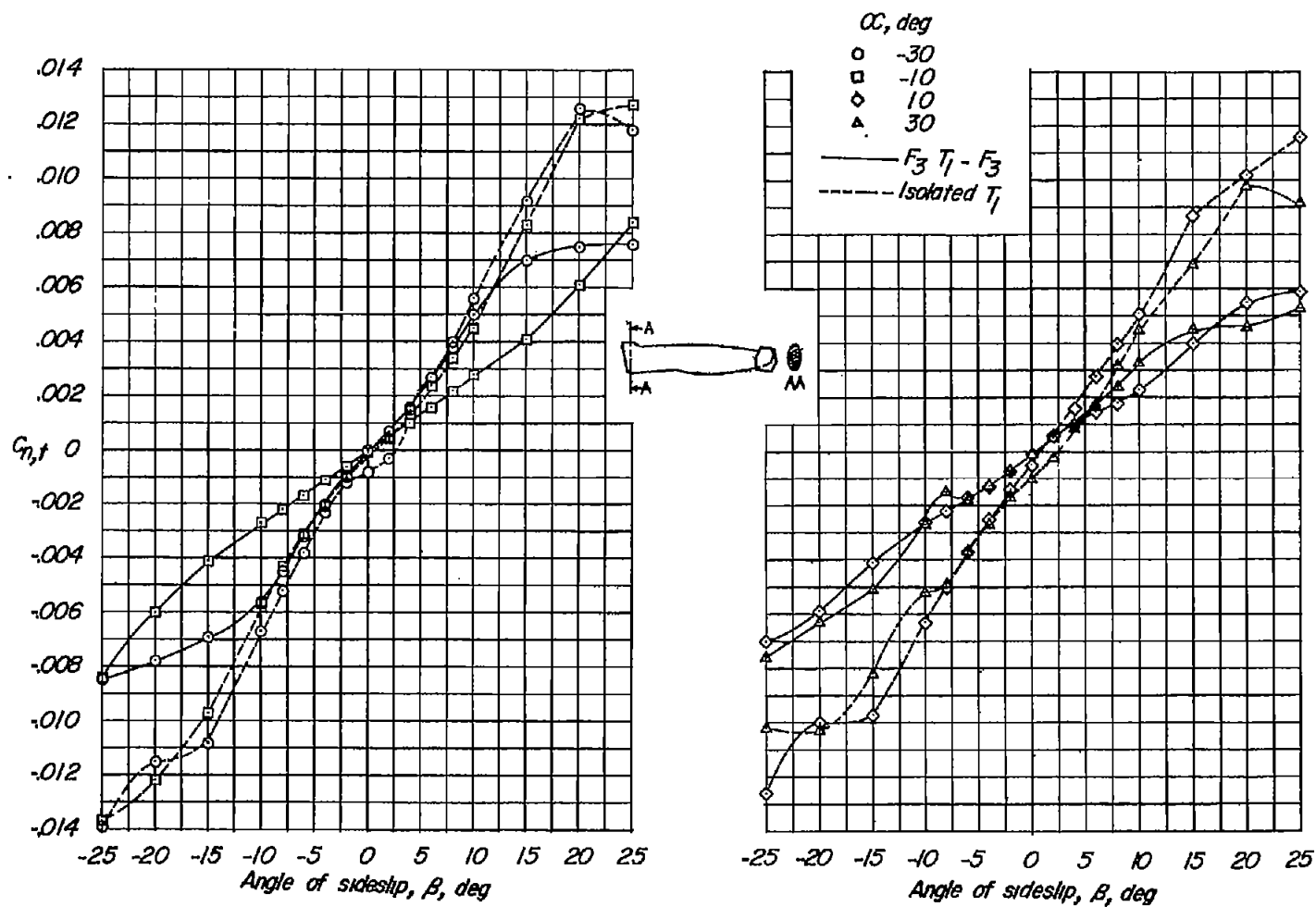
(a) Configuration F_1 .

Figure 8.- Variation with sideslip angle of yawing moment of isolated tail and the tail contribution to the yawing moment at several angles of attack.



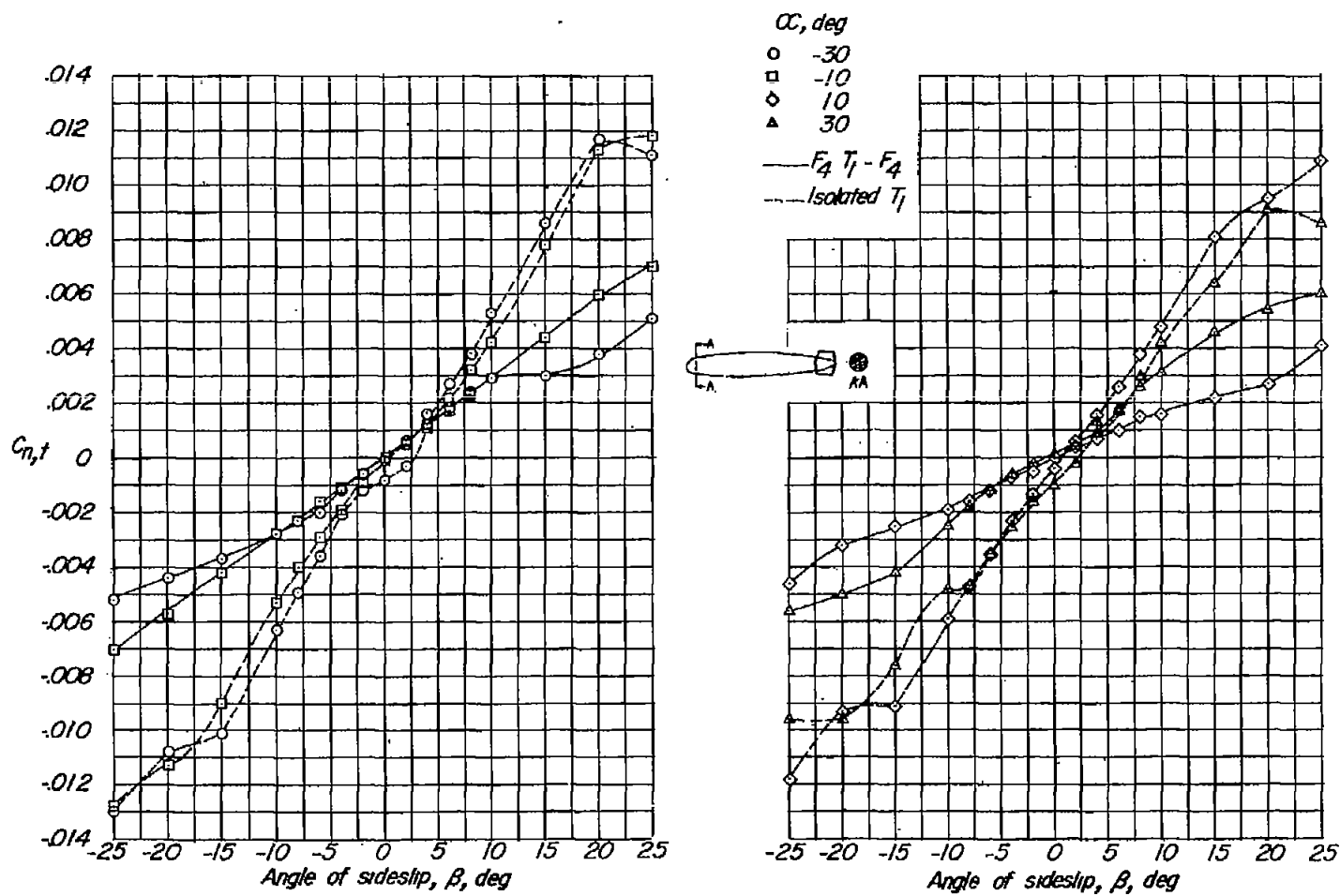
(b) Configuration F_2 .

Figure 8.- Continued.



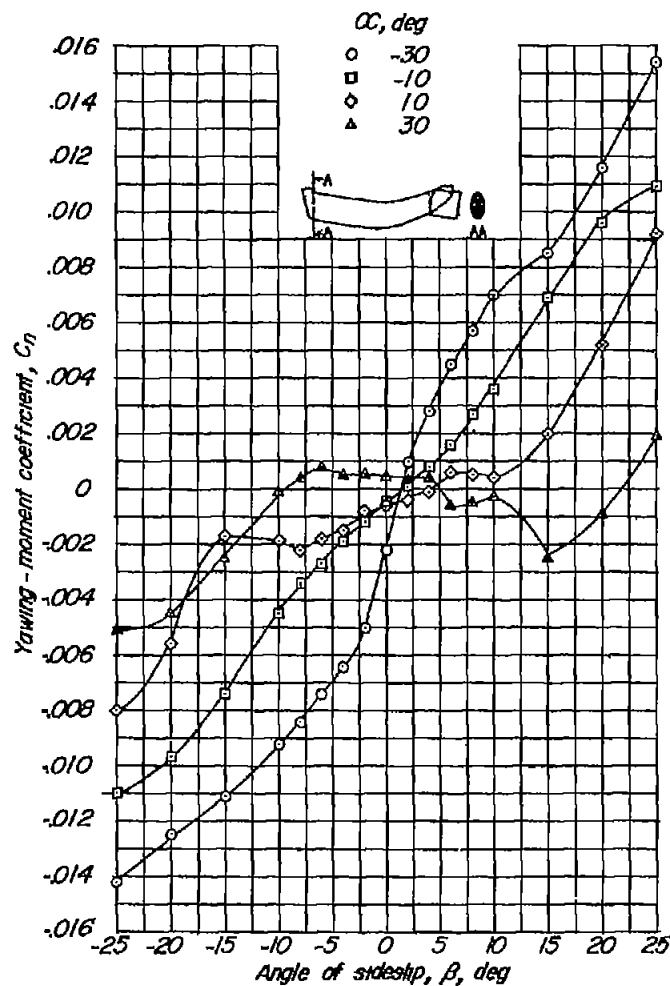
(c) Configuration F_3 .

Figure 8.- Continued.

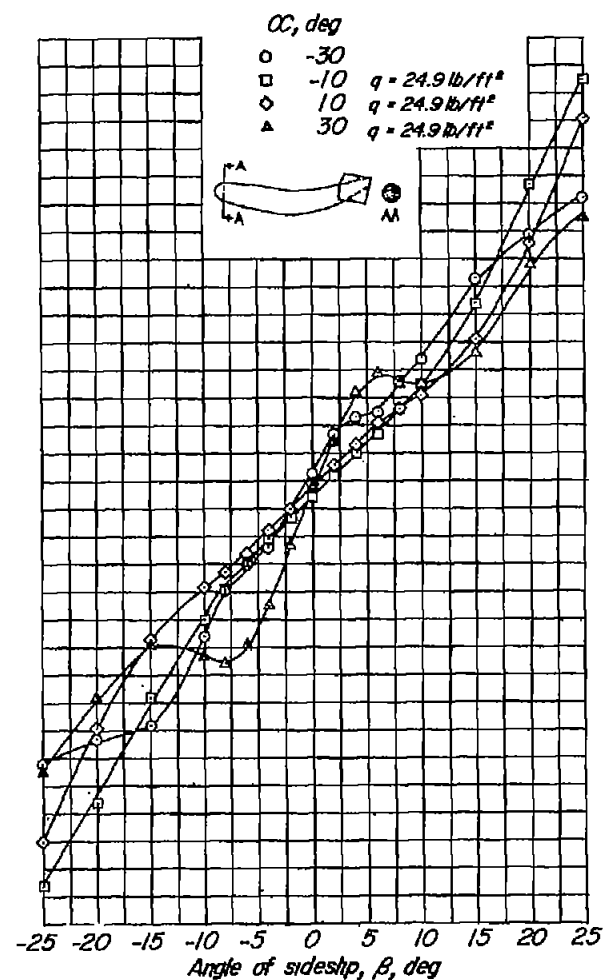


(d) Configuration F_4 .

Figure 8.- Concluded.

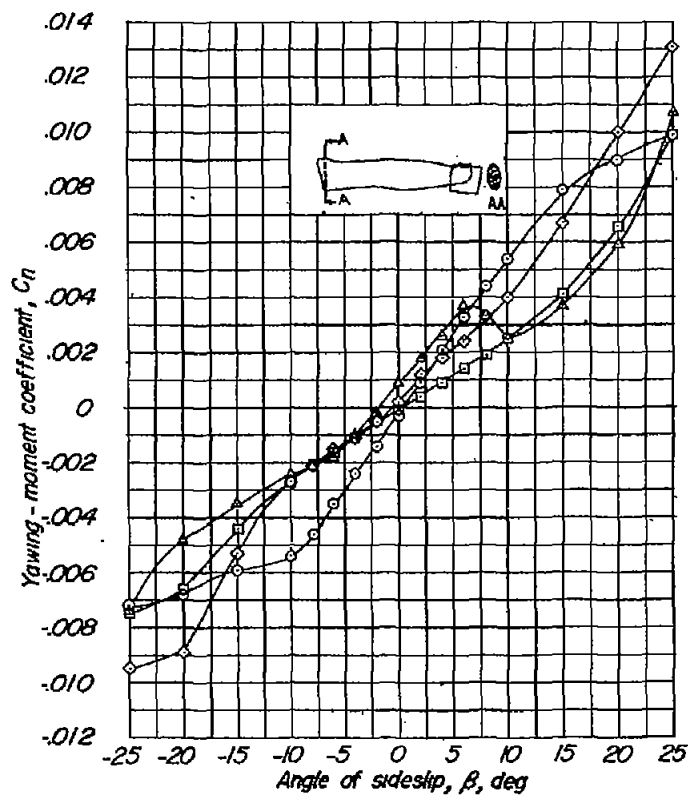


(a) Configuration F_1T_2 .

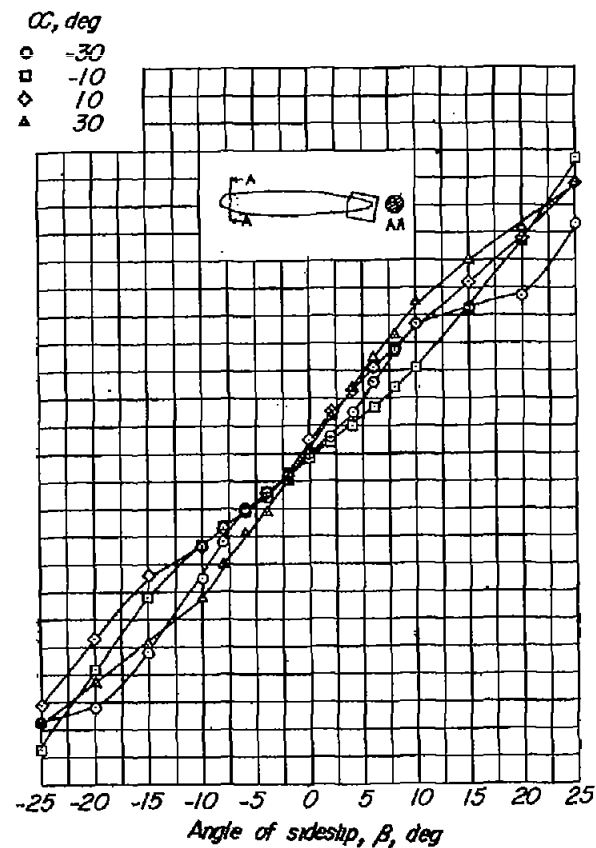


(b) Configuration F_2T_2 .

Figure 9.- Yawing-moment characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.



(c) Configuration F_3T_2 .



(d) Configuration F_4T_2 .

Figure 9.- Concluded.

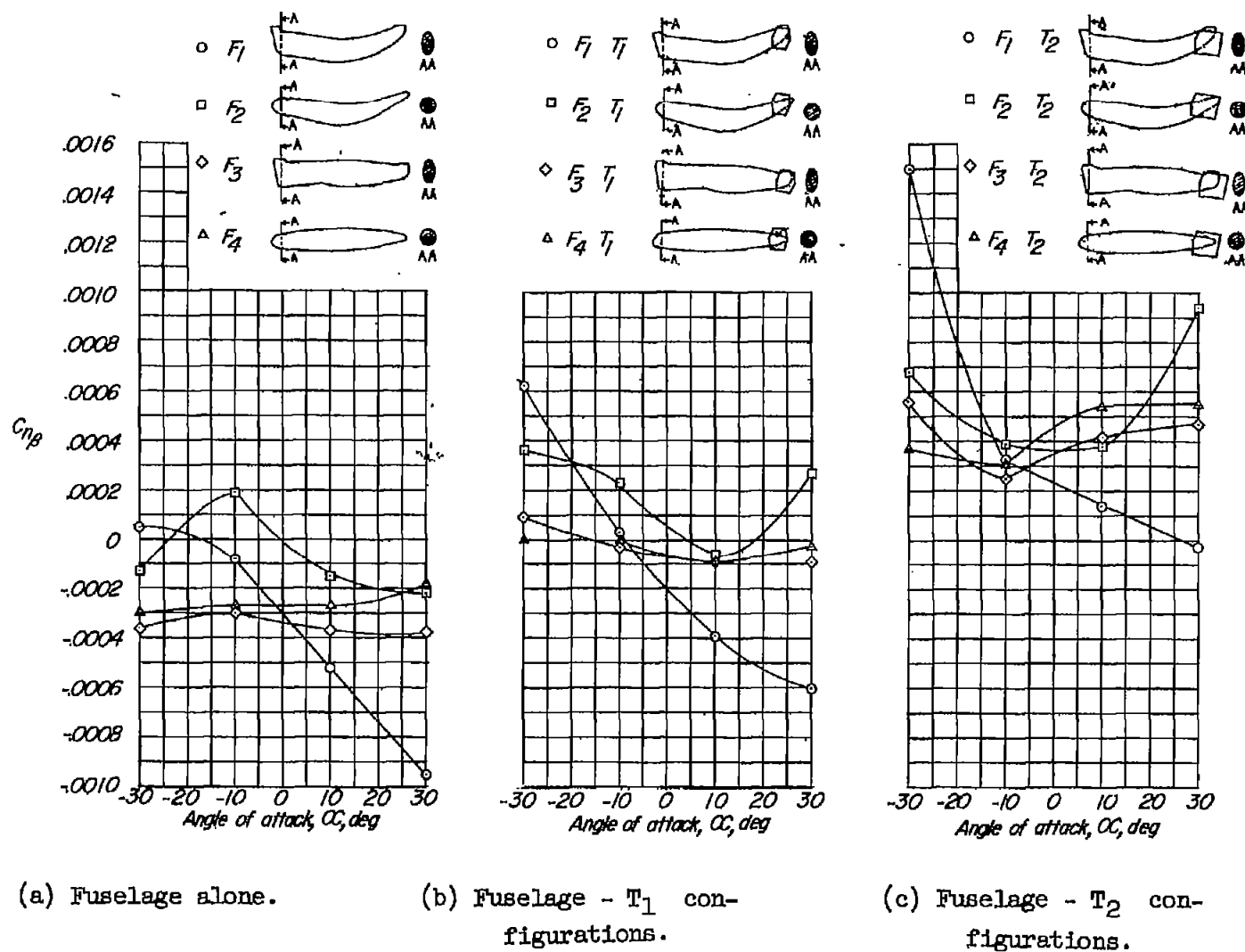


Figure 10.- Comparison of the variation of directional stability parameter $C_{n\beta}$ ($\beta = 0^\circ$) with angle of attack for the fuselage models with and without T_1 and T_2 .

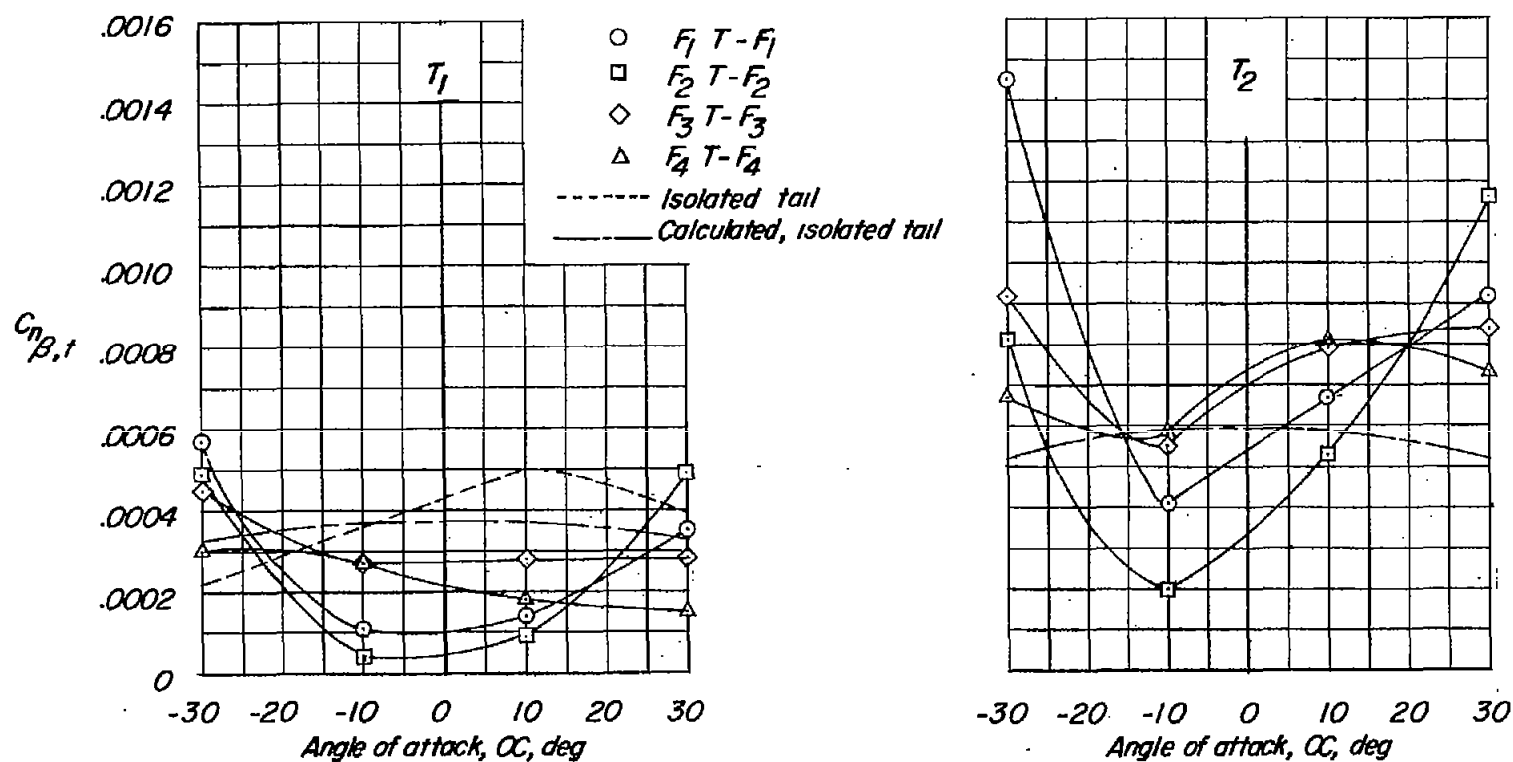


Figure 11.- Comparison of the variation of the directional stability parameter $C_{n_{\beta}}$ ($\beta = 0^\circ$) for the isolated tails, calculated isolated tail T_1 , and for the tail contribution.

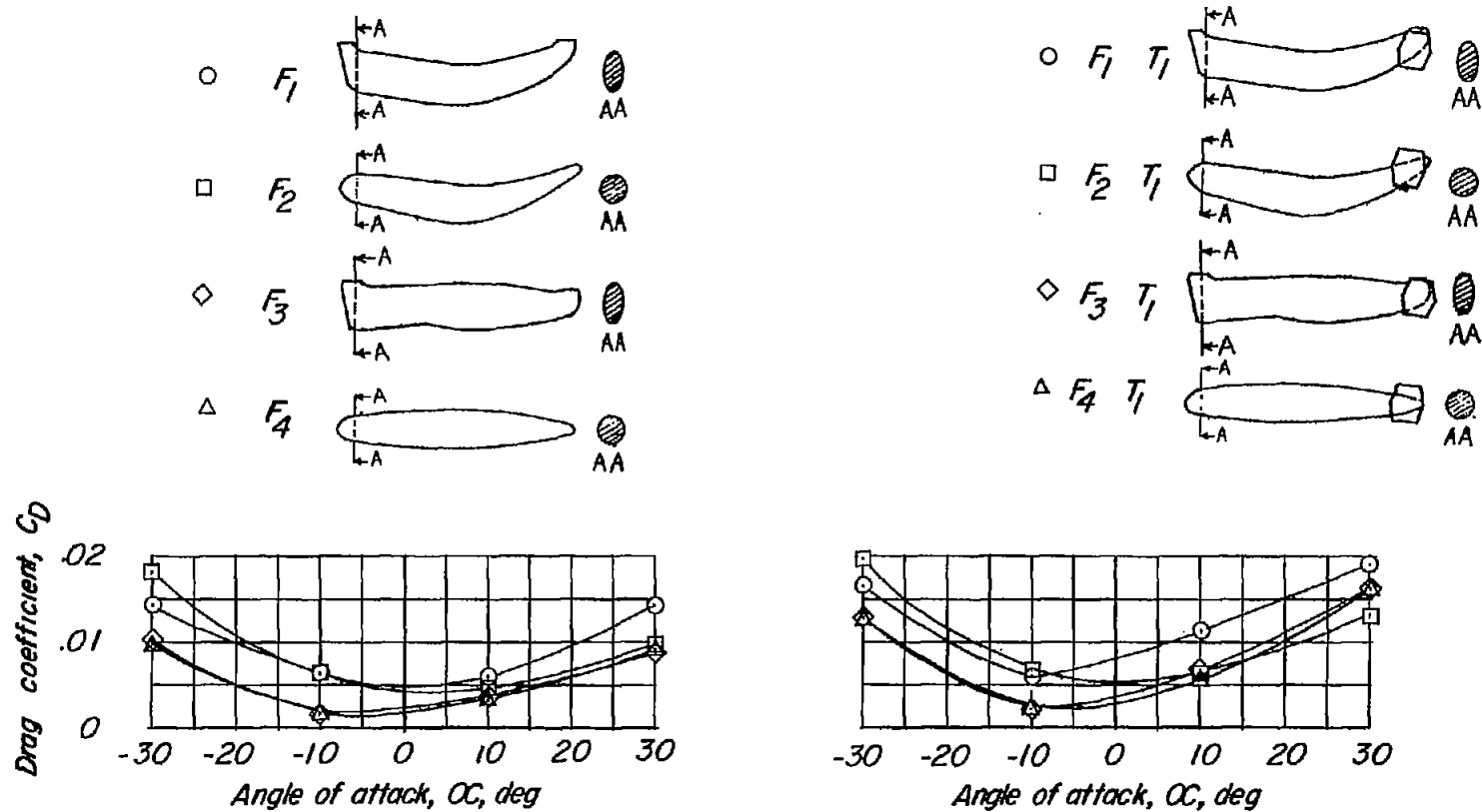


Figure 12.- Variation of drag coefficient with angle of attack ($\beta = 0$) for the fuselages with and without T_1 .

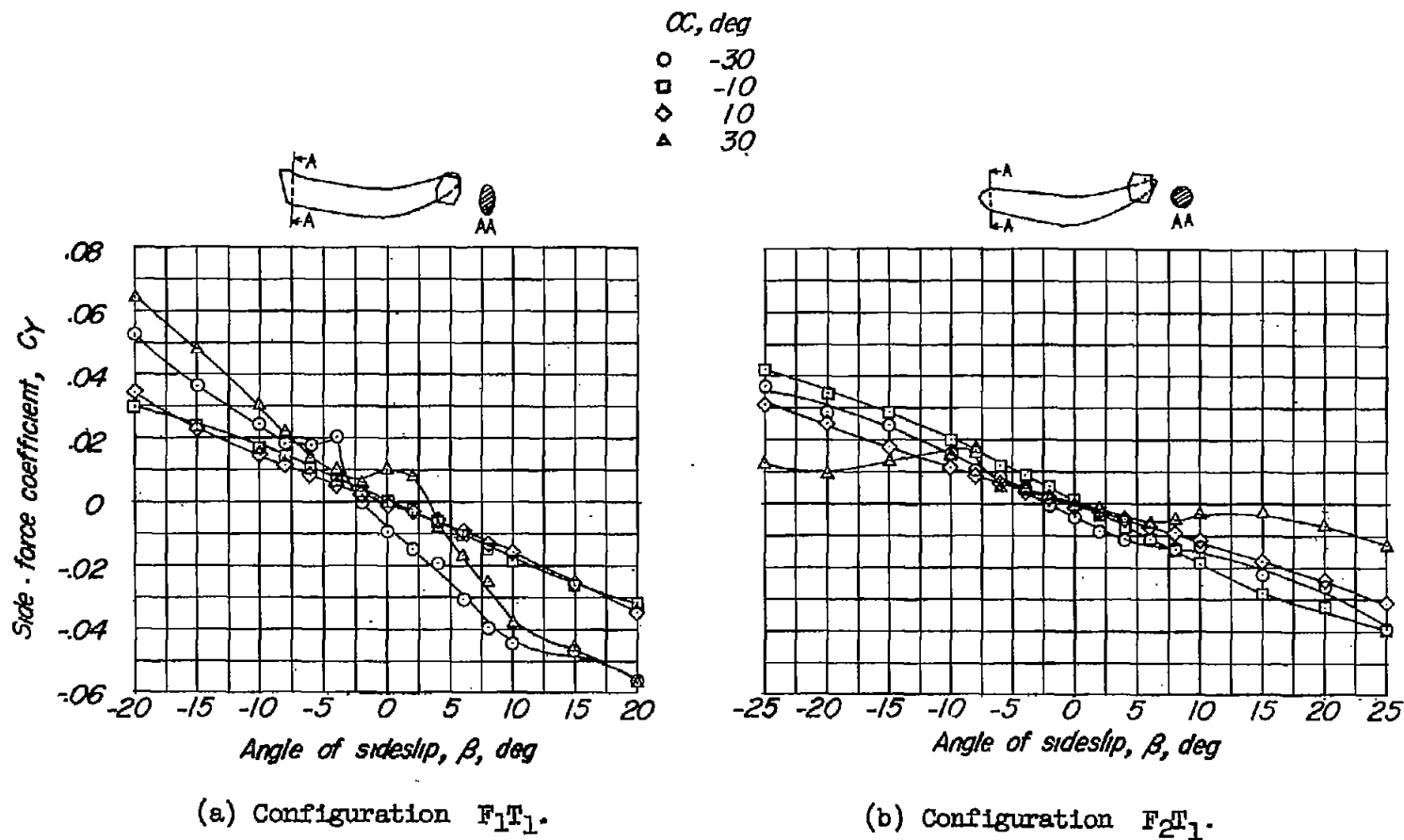


Figure 13.- Side-force characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.

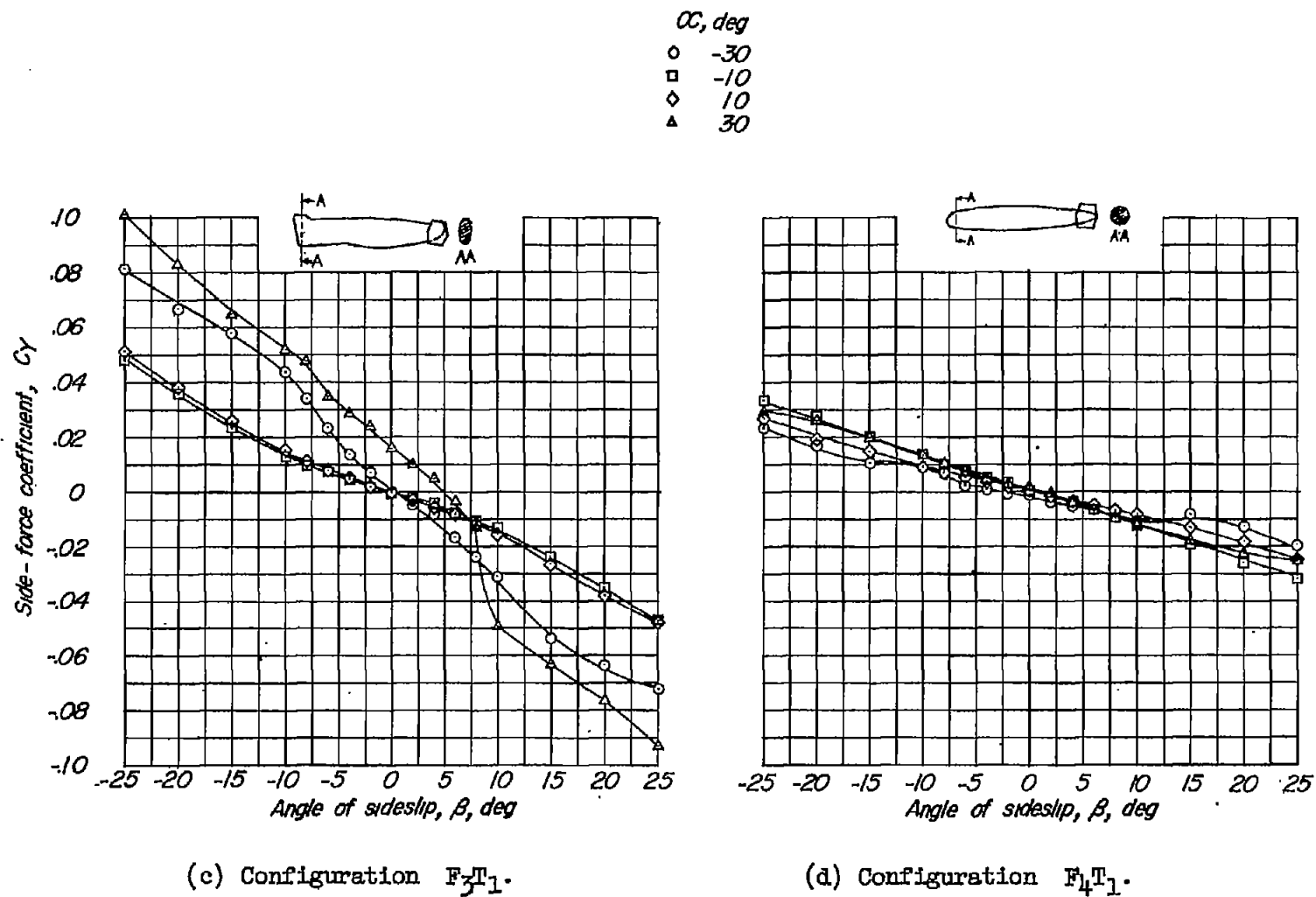


Figure 13.- Concluded.

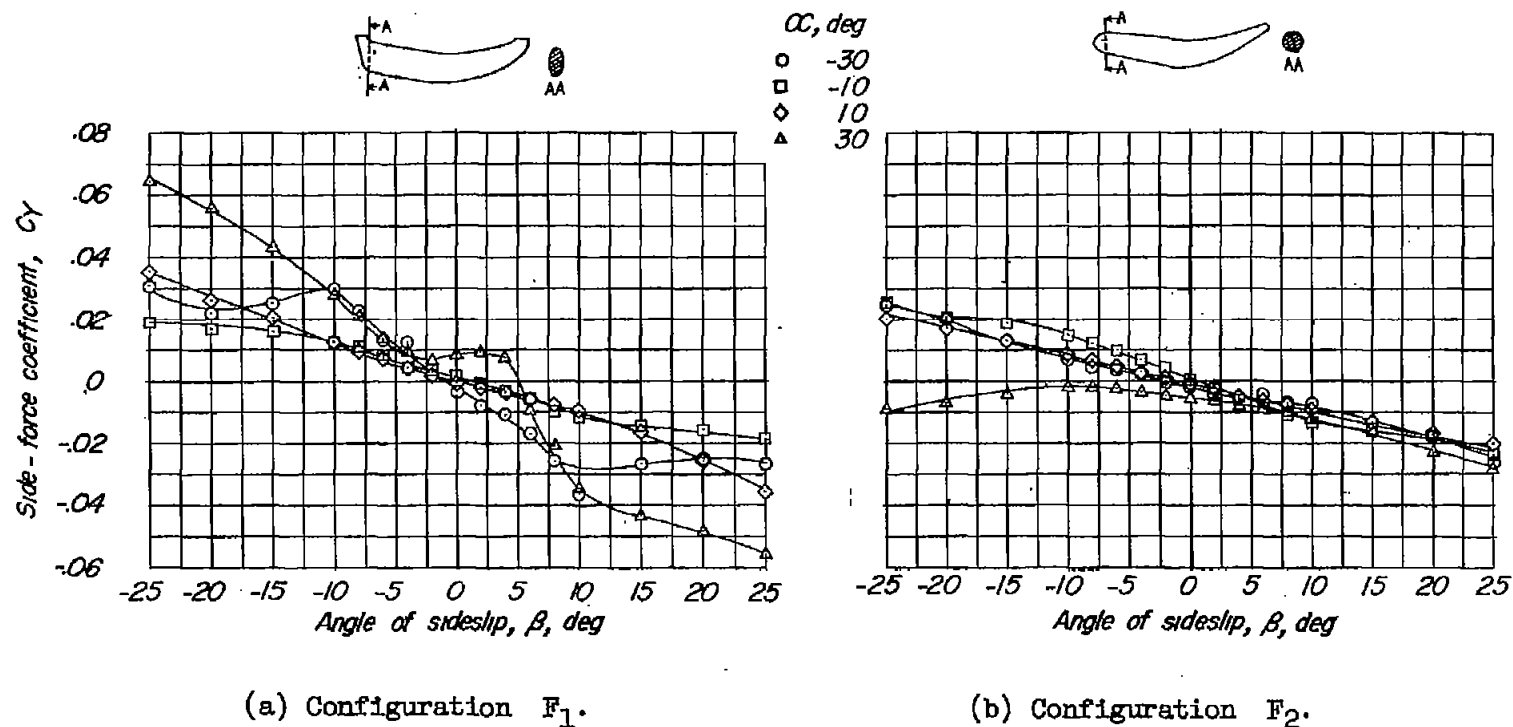


Figure 14.- Side-force characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.

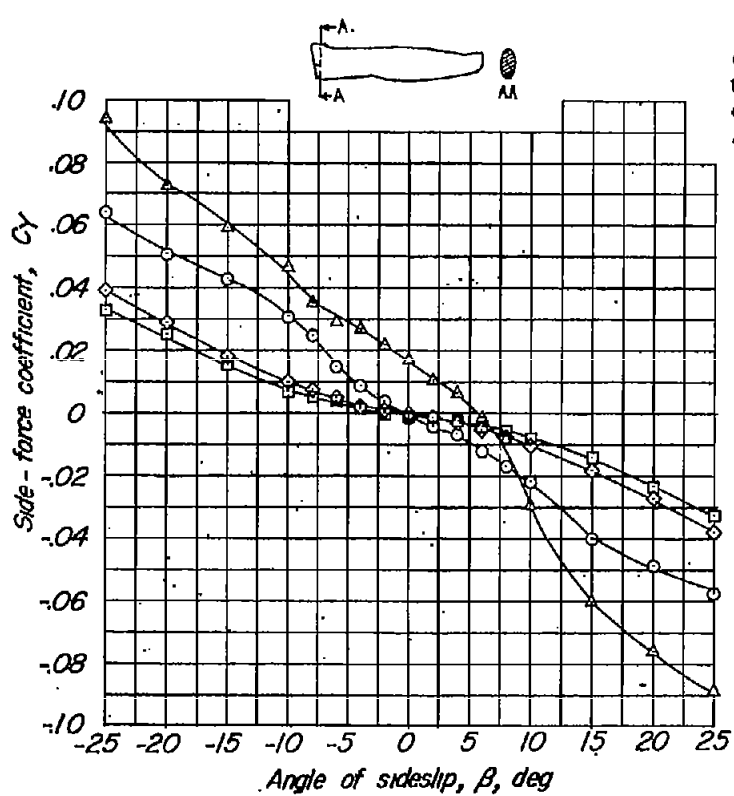
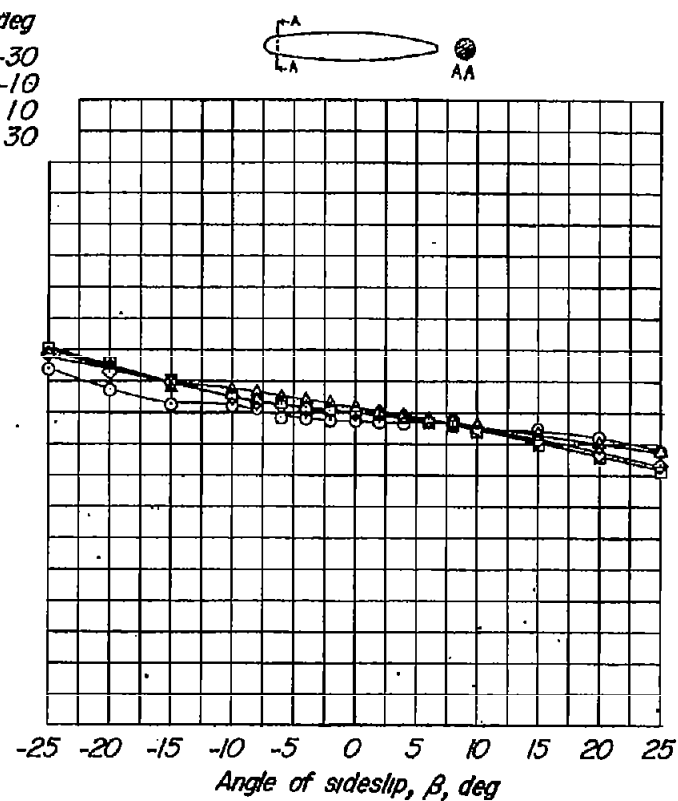
(c) Configuration F_3 .(d) Configuration F_4 .

Figure 14.- Concluded.

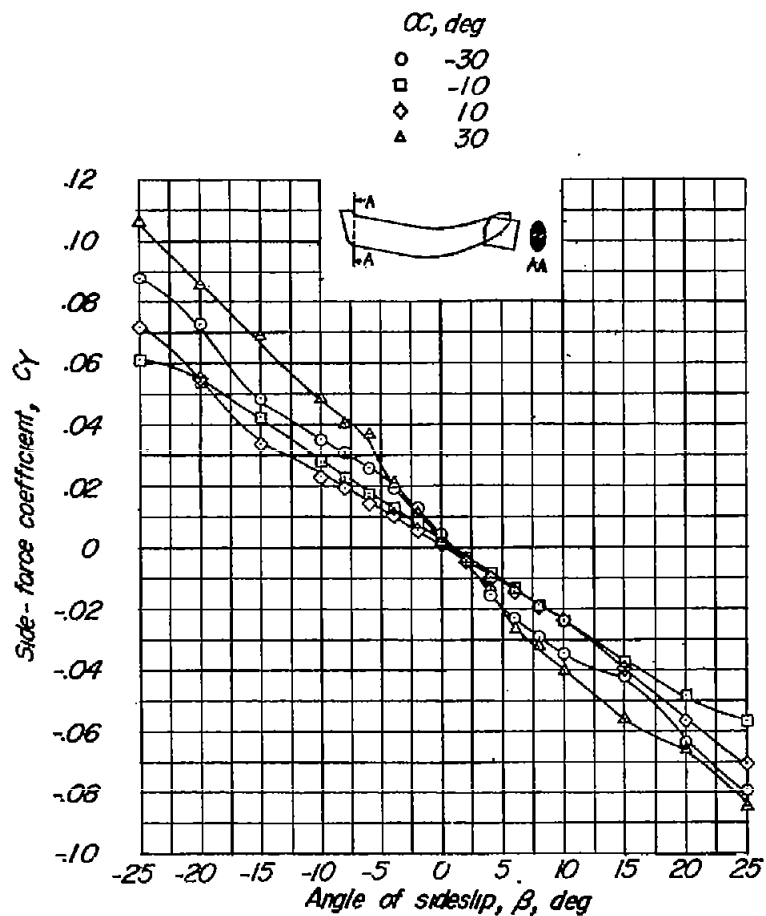
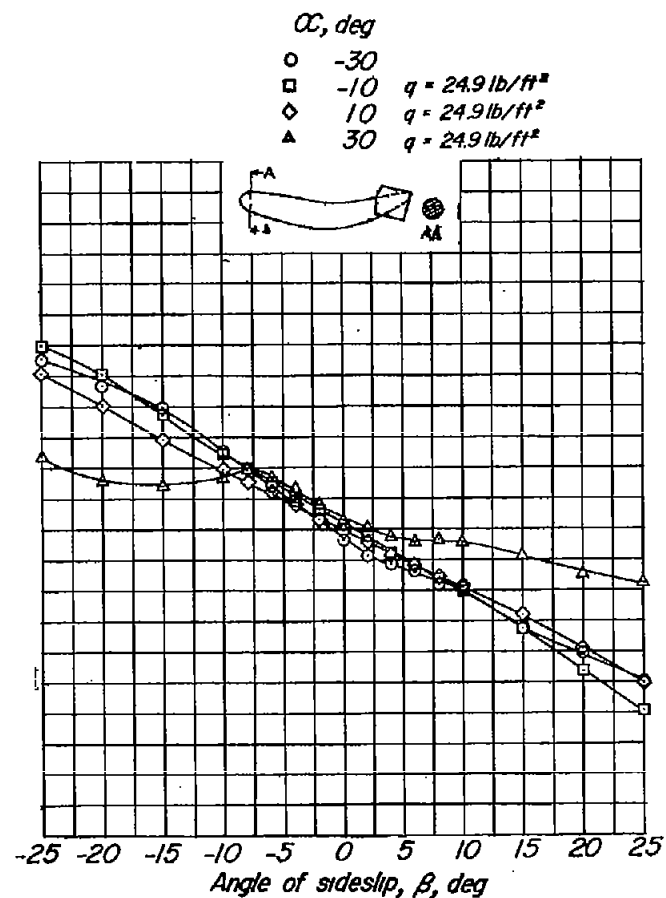
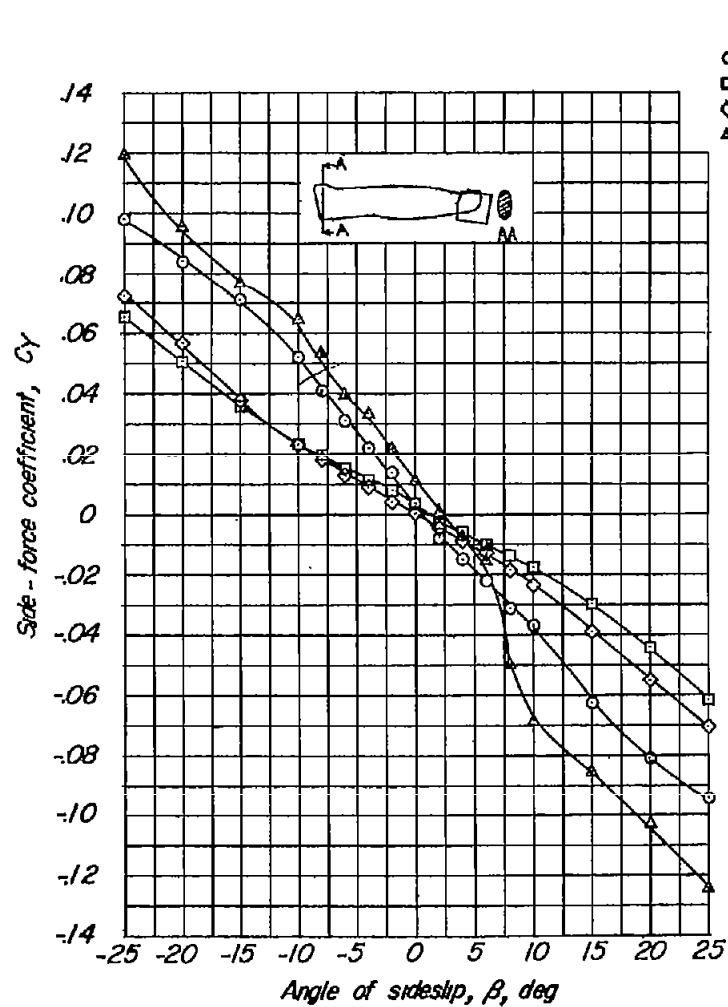
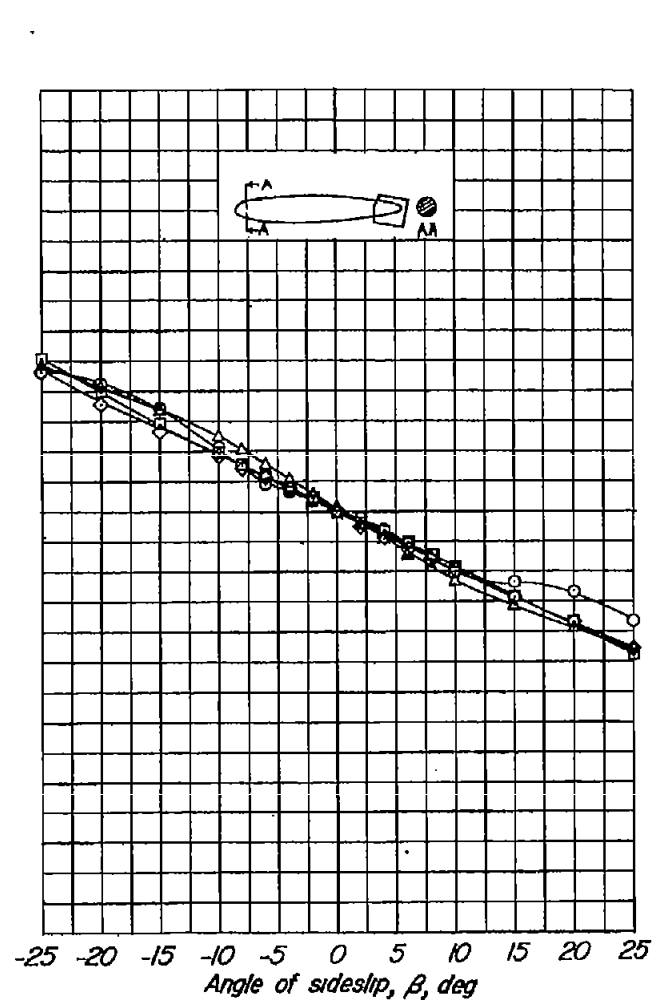
(a) Configuration F_1T_2 .(b) Configuration F_2T_2 .

Figure 15.- Side-force characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.



(c) Configuration F_3T_2 .



(d) Configuration F_4T_2 .

Figure 15.- Concluded.

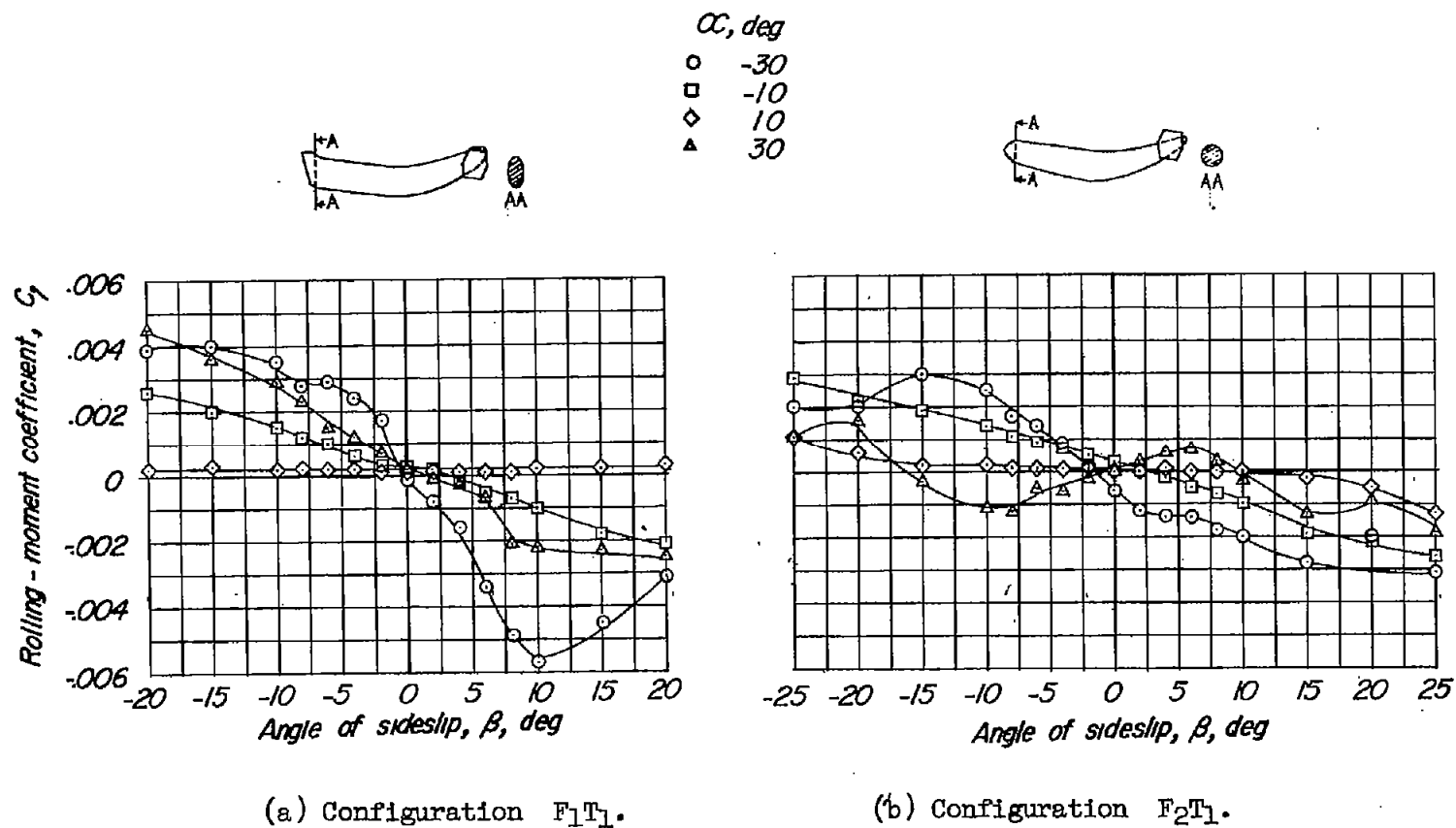
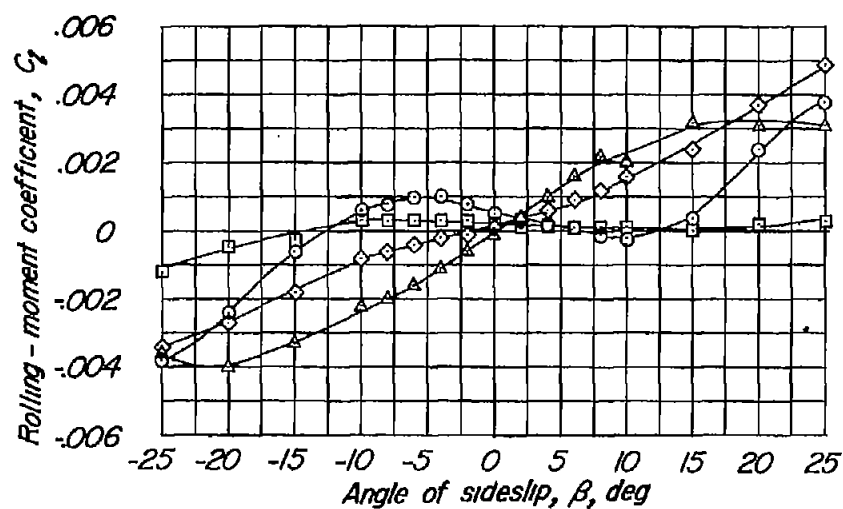
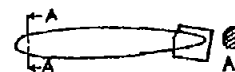
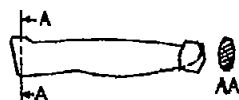
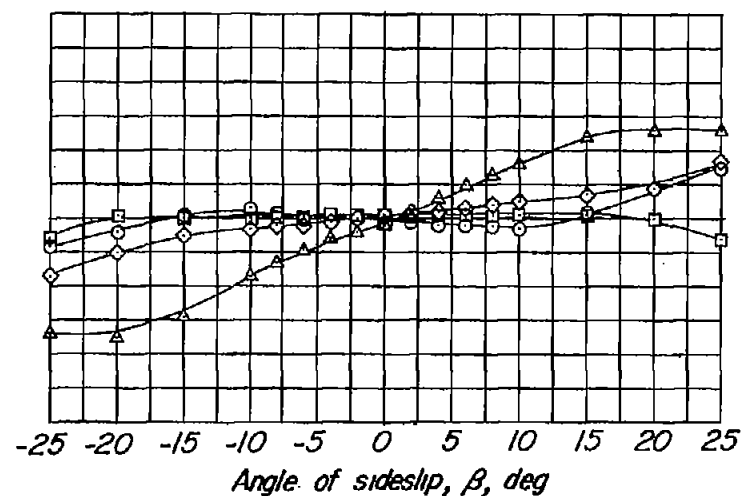


Figure 16.- Rolling-moment characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.

α , deg
 ○ -30
 □ -10
 ◇ 10
 ▲ 30



(c) Configuration F_3T_1 .



(d) Configuration F_4T_1 .

Figure 16.- Concluded.

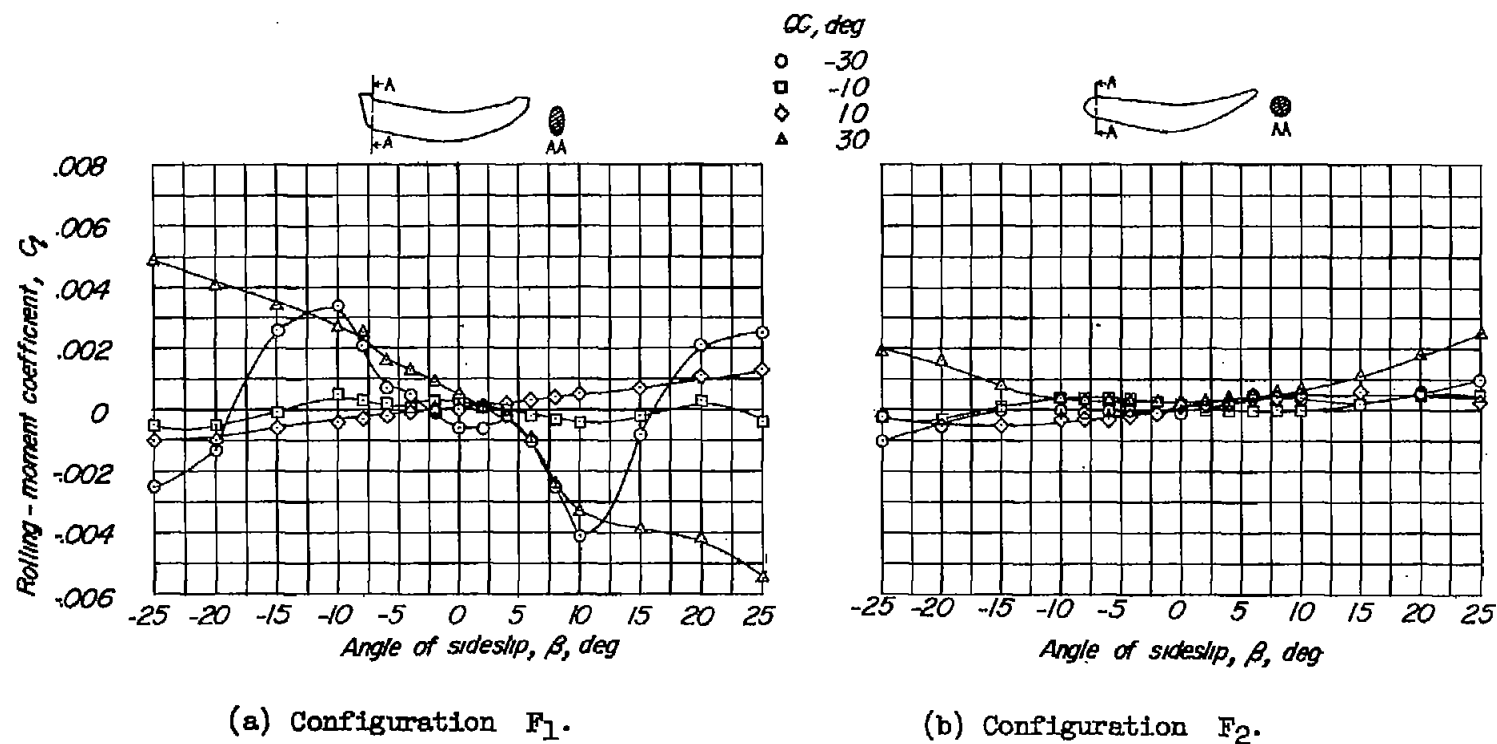


Figure 17.-- Rolling-moment characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.

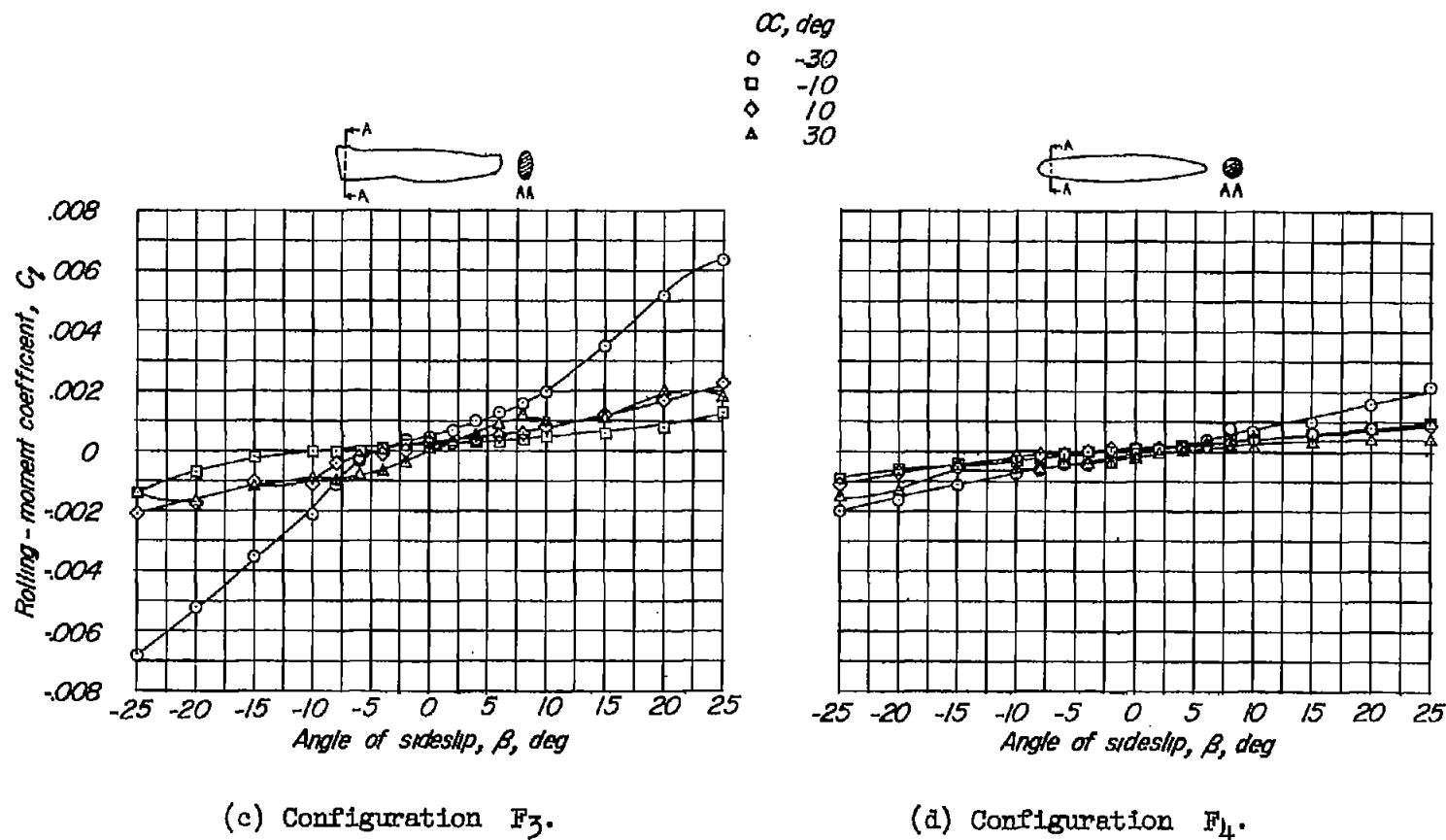


Figure 17.- Concluded.

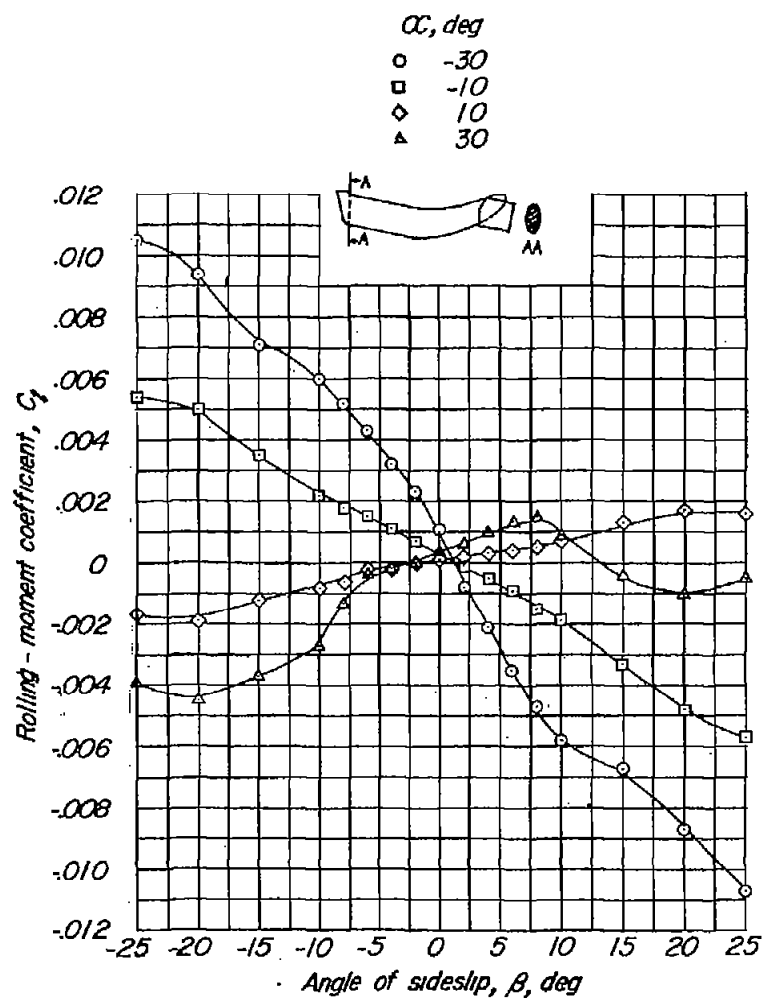
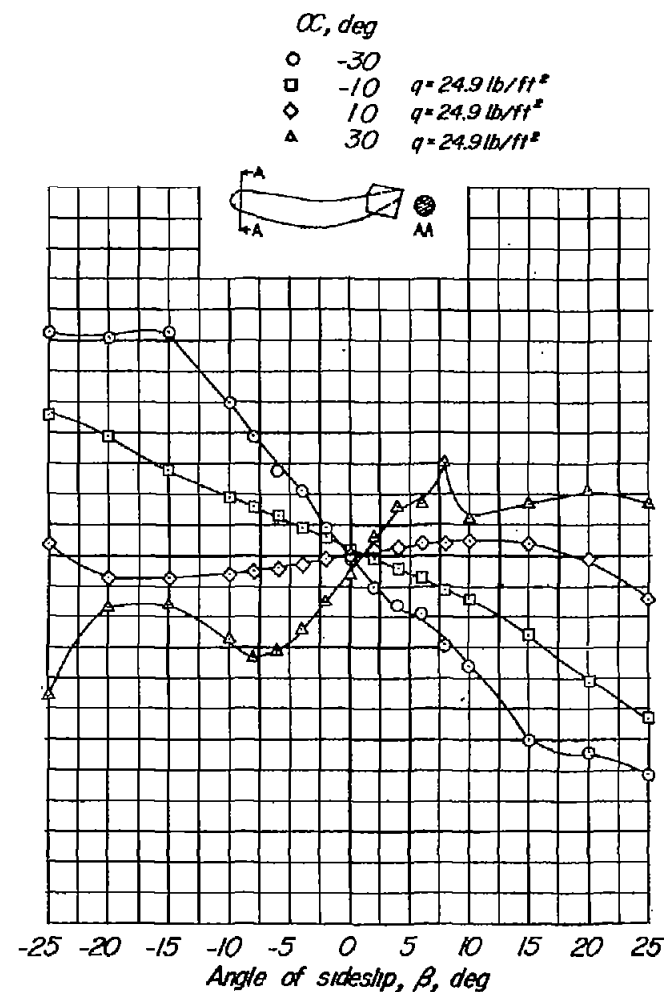
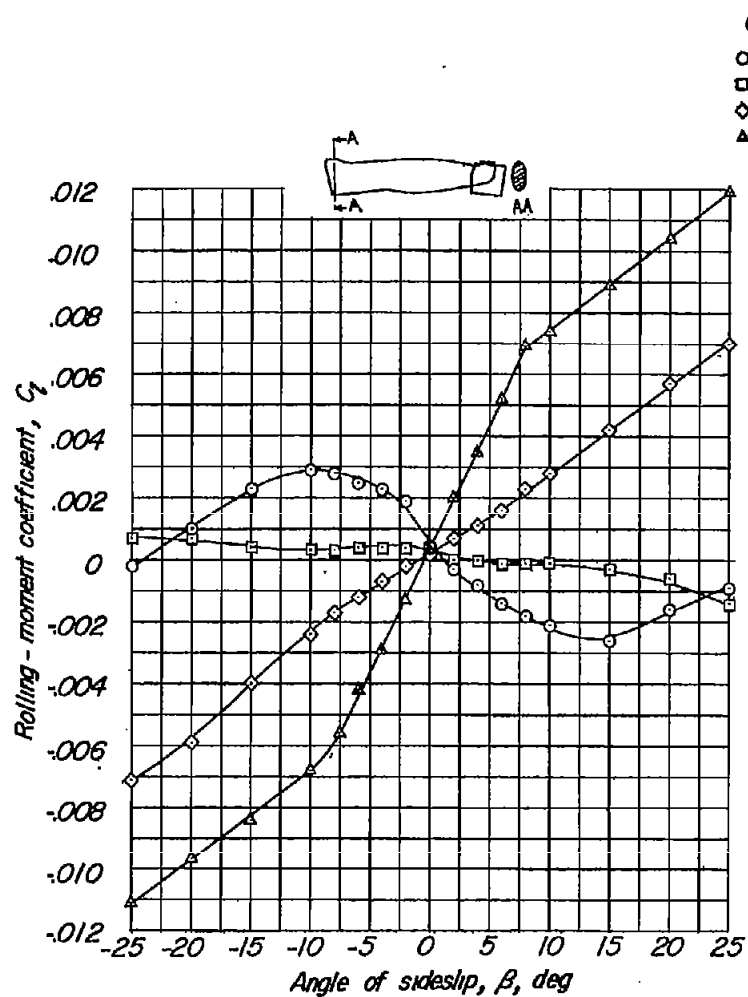
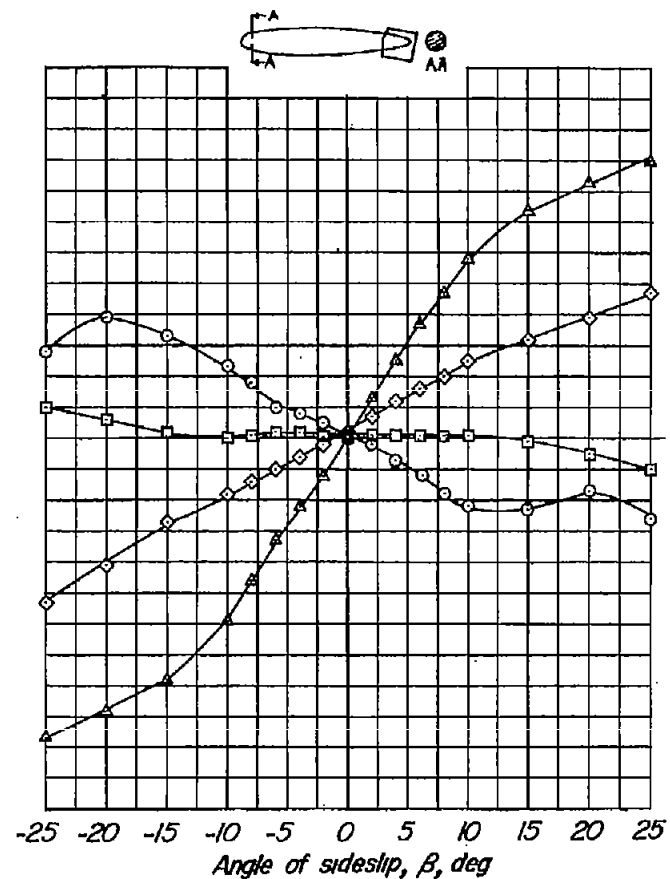
(a) Configuration F_1T_2 .(b) Configuration F_2T_2 .

Figure 18.- Rolling-moment characteristics in sideslip at several angles of attack for various configurations of a nonoverlap-type helicopter fuselage model.



(c) Configuration F₃T₂.



(d) Configuration F₄T₂.

Figure 18.- Concluded.